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Final Report

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Castine, ME 04420**

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14. ABSTRACT This report describes the results of tasks completed by Maine Maritime Academy engineering and marine transportation faculty to investigate and develop stationary and ship service fuel cell (SSFC) power plant coursework for United States Navy (USN) operators, engineers, and marine integrators, under Office of Naval Research (ONR) grant number N00014-03-1-0240. This work has been performed within a broad multi-year program (BIW Marine Fuel Cell Verification-Trainer proposal to ONR, 21 August 2002) to confirm the viability of fuel cell based marine power plants through the operation and monitoring of equipment ashore and at-sea.				
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Table of Contents

1. Executive Summary.....	2
2. Operator Training Curriculum.....	3
2.1 Classroom Modules	
2.2 Laboratory and Training Simulator Modules	
2.3 Shipboard Modules	
3. Learning Technology Recommendations.....	38
3.1 Classroom Modules	
3.2 Laboratory and Training Simulator Modules	
3.3 Shipboard Modules	
4. Applicable Navy Training Standards Overview.....	44
5. Interface with University of Maine Engineering-based Course....	46
6. Summary.....	47
7. References.....	48
Appendix.....	49

1.0 Executive Summary

This report describes the results of tasks completed by Maine Maritime Academy engineering and marine transportation faculty to investigate and develop stationary and ship service fuel cell (SSFC) power plant coursework for United States Navy (USN) operators, engineers, and marine integrators, under Office of Naval Research (ONR) grant number N00014-03-1-0240. This work has been performed within a broad multi-year program (BIW Marine Fuel Cell Verification-Trainer proposal to ONR, 21 August 2002) to confirm the viability of fuel cell based marine power plants through the operation and monitoring of equipment ashore and at-sea.

The report provides detailed lesson boards of comprehensive modules for classroom, laboratory, training simulator, and shipboard training.

The modules include suggested topics, content, and supplemental learning materials. Recommended instructor resources and references for module presentations and exercises are provided for each training area.

Results of research into emerging learning technologies, in the forms of recommended hardware, software, communications networks, supplemental materials, and simulator specifications are reported with recommendations and reference sources.

The report includes a description of the application of operator training module content in support for development of an engineering course in fuel cell power plants at the University of Maine developed under a parallel separate proposal.

Sources of information to configure and deliver the operator training curriculum in accord with navy training content guidelines and standards are provided.

With the anticipation that up to several years' delay will occur between the time of this report and the maturity of the SSFC technology and its plant operations, suggestions for use of the information in this report and steps toward future curriculum development are provided throughout.

2.0 Operator Training Curriculum

Training modules are divided into three lesson groups: Classroom, Laboratory and Simulator, and Shipboard modules. Each module is designed with flexible content such that the material can be presented and trainees given hands on experience from a minimum of a five-day or 10-day immersion course. The length of the course will depend on the learning outcomes requirements and preparation and skills level objectives of the trainees attending.

The training modules are considered comprehensive to the level of documented and firm understanding of Ship Service Fuel Cell (SSFC) operations as of the date of this report. The supplemental materials references provide future course developers extensive foundation material, for direct use in their training modules.

Most of the module contents, and especially the supplemental materials, reference FuelCell Energy (FCE, the manufacturer) documentation are subject to change as the Direct Fuel Cell (DFC) SSFC plant technology matures in the laboratory and at sea trials. Therefore, references to FCE documentation for module content, illustrations, and suggested readings are for reference only, given as foundation sources available at the time of this project.

The supplemental references to published materials are considered the best references at the time of this project research. However, fuel cell technology is changing rapidly in both development and application. Future course developers are advised to canvass the latest publishers and information web sites for the most current information at the time of the course development.

It is assumed that the manufacturer will have developed an operator's manual in time for the operator curriculum training, even if offered as a work in progress as field experience accumulates. The operator manual, together with other supplemental materials developed by the instructor, will complete the learning materials required in the modules.

2.1 Classroom Modules

The classroom training modules provide background and introduction to the Direct Fuel Cell Ship Service Fuel Cell (DFC SSFC) for future operators. These modules would fill a 2- to 4- day lecture and presentation series (depending on length of training course) preparing the trainees for further laboratory and simulator training and then shipboard SSFC training.

The classroom modules are presented in lesson board form. The reference numbers on supplemental materials lists refer to sources listed numerically in the Reference page of this section.

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Classroom Module #1

Page 1 of 3

Topic	Discussion/Slides/Notes	Supplemental Material
• Fuel Cell Technology Overview	<ul style="list-style-type: none"> • Definition • Schematic construction and operation 	Text: 1, 2, 3, 7 Video: 7, 8 Data: 1, 2, 3 Illustrations: 1, 2, 3 Readings: 1, 2, 7
• Fuel Cell Development	<ul style="list-style-type: none"> • Early History <ul style="list-style-type: none"> • Grove's 'Gaseous Voltaic Battery' - 1839 • 19th century incremental development • 20th Century Development <ul style="list-style-type: none"> • Advances in electrochemistry and many fuel cell types • Progression to higher temperature, higher efficiency, higher electrical power processors • Apollo space missions 	Text: 1, 3 Video: Data: Illustrations: 1, 3 Readings: 1, 2
• Commercial fuel cells today	<ul style="list-style-type: none"> • Portable power - small battery replacement • Transportation - internal combustion replacement • Stationary power generation - base load and back-up power 	Text: 1, 2, 3, 7 Video: Data: Illustrations: 1, 3, 7 Readings: 1, 7
• Trends	<ul style="list-style-type: none"> • Improved volumetric and gravimetric densities • Reduced purchase cost • Both micro and macro development 	

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Classroom Module #1	Day/Time	Page 2 of 3
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Topic	Discussion/Slides/Notes	Supplemental Material
• Fuel Cell Types	<ul style="list-style-type: none"> • Commercially available fuel cells 	Text: 1, 2, 3, 7 Video: 7 Data: 1, 3 Illustrations: 1, 2, 3, 7 Readings: 1, 2, 7
• Proton Exchange Membrane Fuel Cell	<ul style="list-style-type: none"> • Theory of operation • Typical construction and operation • Typical output characteristics 	
• Alkaline Fuel Cell	<ul style="list-style-type: none"> • Theory of operation • Typical construction and operation • Typical output characteristics 	Text: 1, 3 Video: 7 Data: 1, 3 Illustrations: 1, 3, 7 Readings: 1, 2
• Phosphoric Acid Fuel Cell	<ul style="list-style-type: none"> • Theory of operation • Typical construction and operation • Typical output characteristics 	Text: 1, 3 Video: Data: 1, 3 Illustrations: 1, 3, 7 Readings: 1, 2

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Classroom Module #1	Day/Time	Page 3 of 3
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Topic	Discussion/Slides/Notes	Supplemental Material
• Molten Carbonate Fuel Cell	<ul style="list-style-type: none"> • Theory of operation • Typical constriction and operation • Typical output characteristics 	Text: 1, 2, 3 Video: 8 Data: 1, 3, 8 Illustrations: 1, 3, 8 Readings: 1, 2, 8
• Solid Oxide Fuel Cell	<ul style="list-style-type: none"> • Theory of operation • Typical constriction and operation • Typical output characteristics 	Text: 1, 2, 3 Video: Data: 1, 3 Illustrations: 1, 3 Readings: 1, 2
• Summary - Comparative performance and operating characteristics of fuel cell types	<ul style="list-style-type: none"> • Tabular presentation 	Text: 1, 2, 3 Video: Data: 1, 3 Illustrations: Readings: 1, 2

Course _____
 Instructor _____

Location _____
 Date _____

Lesson Classroom Module #2	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
<ul style="list-style-type: none"> • Fuel cells in Power Generation • Stationary Power 	<ul style="list-style-type: none"> • Replaces: Steam turbine generation units, other central electric generation sources • Advantages <ul style="list-style-type: none"> • Fuel efficiency, low maintenance, low emissions, CH&P opportunity • Disadvantages <ul style="list-style-type: none"> • Purchase cost, unit start up (heat soak) time, low volumetric power densities 	Text: 1, 2, 3, 6, 9 Video: Data: 2, 3 Illustrations: 1, 3 Readings: 1, 6, 9
<ul style="list-style-type: none"> • Emergency Power 	<ul style="list-style-type: none"> • Replaces: Battery banks, diesel gen-sets, other UPS systems • Advantages <ul style="list-style-type: none"> • Fuel efficiency, low maintenance, low emissions • Disadvantages <ul style="list-style-type: none"> • Purchase cost, hot standby only, low volumetric power densities 	Text: 1, 6 Video: Data: 7 Illustrations: 1 Readings: 1, 6

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Classroom Module #3	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
<ul style="list-style-type: none"> Fuel cell thermodynamic and electrochemical processes 	<ul style="list-style-type: none"> Introduction to electrochemical processes Gibbs equation Nernst equation Key energy conversion performance variables 	Text: 1, 2, 3 Video: Data: 1, 2, 3 Illustrations: 1 Readings: 1, 3
<ul style="list-style-type: none"> Comparisons to thermodynamics of combustion-source heat engine processes 	<ul style="list-style-type: none"> Review of Carnot Cycle Advantage of isothermal, quasi-reversible processes 	Text: 1, 2, 3 Video: Data: 1, 2, 3 Illustrations: 1, 3 Readings: 1, 3
<ul style="list-style-type: none"> Plant engineering analysis 	<ul style="list-style-type: none"> Fuel-to-electricity efficiency equation Loss mechanisms Mass and energy balance analysis Key fuel cell engineering performance variables 	Text: 1, 2, 3, 10 Video: Data: 1 Illustrations: 1, 3 Readings: 1, 3, 10

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Classroom Module #4	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
• Molten Carbonate Fuel Cell for Ship Service Fuel Cell Power	<ul style="list-style-type: none"> • Operating characteristics of typical MCFC power (>250kW) plant • Process diagram • Typical performance characteristics 	Text: 1, 3 Video: 8 Data: 1, 3, 8 Illustrations: 1, 3, 8 Readings: 1, 8
• General marine applications considerations	<ul style="list-style-type: none"> • Fuel cell fit to ship service power requirements <ul style="list-style-type: none"> • Load profiles • Marine fuels in DFC units • Emissions • Naval warfare requirements • MCFC comparative advantages for ship service power <ul style="list-style-type: none"> • 'Internal' fuel reforming, fuel efficiency, proven field experience 	Text: 5, 6, 11, 12, 14, 15, 17 Video: Data: 5, 12 Illustrations: 5 Readings: 5, 6, 11, 15, 16, 17

Course _____
 Instructor _____

Location _____
 Date _____

Lesson Classroom Module #5	Day/Time	Page 1 of 5
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Topic	Discussion/Slides/Notes	Supplemental Material
• SSFC Systems	<ul style="list-style-type: none"> • Overview of key systems • System diagrams 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• Fuel Processing	<ul style="list-style-type: none"> • Function • Key components • Process system I/O • Typical operating ranges • Control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• Fuel Cell Stack	<ul style="list-style-type: none"> • Function • Key assembly components • Process system I/O • Typical operating ranges • Control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Classroom Module #5	Day/Time	Page 2 of 5
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Topic	Discussion/Slides/Notes	Supplemental Material
• MBOP	<ul style="list-style-type: none"> • Subsystems and functions <ul style="list-style-type: none"> • Key components • Process system I/O • Typical operating ranges • Control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• EBOP	<ul style="list-style-type: none"> • Subsystems and functions <ul style="list-style-type: none"> • Key components • Process system I/O • Typical operating ranges • Control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• Monitoring and control systems	<ul style="list-style-type: none"> • Subsystems and functions <ul style="list-style-type: none"> • Key components • Layout and HMI 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Classroom Module #5	Day/Time	Page 3 of 5
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Topic	Discussion/Slides/Notes	Supplemental Material
• SSFC Operations	<ul style="list-style-type: none"> • Operations Overview 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• Pre-Startup	<ul style="list-style-type: none"> • Procedures overview • Flow diagrams • Key operating control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• Startup	<ul style="list-style-type: none"> • Procedures overview • Flow diagrams • Key operating control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13

Course _____
 Instructor _____

Location _____
 Date _____

Lesson Classroom Module #5	Day/Time	Page 4 of 5
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Topic	Discussion/Slides/Notes	Supplemental Material
• Steady State Operation	<ul style="list-style-type: none"> • Procedures • Flow diagrams • Key operating control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• Shutdown	<ul style="list-style-type: none"> • Procedures • Flow diagrams • Key operating control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13
• Emergency Shutdown	<ul style="list-style-type: none"> • Procedures • Flow diagrams • Key operating control variables 	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13

Course _____
Instructor _____
Location _____
Date _____

Lesson Classroom Module #5	Day/Time	Page 5 of 5
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Topic	Discussion/Slides/Notes	Supplemental Material
• Safety	<ul style="list-style-type: none">• Hazardous materials• Hazardous conditions• Personal safety and equipment• Plant safety systems	Text: 13 Video: Data: 13 Illustrations: 13 Readings: 13

Course _____
 Instructor _____

Location _____
 Date _____

Lecture Classroom Module #6	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
• Maintenance requirements	<ul style="list-style-type: none"> • Predictive and manual maintenance • Key systems • Key components 	<ul style="list-style-type: none"> • Ref: TBD • Video: TBD • Diagrams: TBD • Illustrations: TBD • Suggested readings TBD
• Codes and Standards	<ul style="list-style-type: none"> • Actual and expected governing standards groups list 	<ul style="list-style-type: none"> • Ref: TBD • Video: TBD • Diagrams: TBD • Illustrations: TBD • Suggested readings TBD

2.2 Laboratory and Training Simulator Modules

The laboratory and simulator training modules provide further background review and introduction to the Direct Fuel Cell Ship Service Fuel Cell (DFC SSFC) operations procedures, maintenance, and safety training for future operators. The lab and simulator training includes hands-on operation of a commercially available bench top fuel cell workstation.

The lab and simulator modules would fill a 3- to 6- day lab and simulator lesson series (depending on length of training course) preparing the trainees for the shipboard SSFC training.

Recommendations for simulator performance, features, and human-machine interface are given in the Learning Technology section (Section 3.0) of this report.

The lab and simulator modules are presented in lesson board form. The reference numbers for supplemental materials lists refer to source listed numerically in the References section of this report.

Note: Maintenance Procedures and Schedules Training

Data available at the time of this report suggest that with present technology a 625kW fuel cell generator set requires about 70 - 75% of the maintenance hours compared to an equivalent heat engine. The potential for crew reduction is significant. Maintenance of fuel cell stacks will almost certainly be repair by replacement partly due to the complexity of dismantling a stack and also because of the limited skill base available. Modular construction will facilitate this. Since no silencers or scrubbers are required the exhaust stack can also be used as a fuel cell stack removal route. Support infrastructure and fuel reformer equipment consists of smaller units. These are the components more likely to fail and can either be repaired or replaced by existing crews.

Maintenance procedures and schedules for the 625kW SSFC are not finalized yet and will be formulated over time as the SSFC technology matures. These procedures and schedules will become part of an immersion course for operators.

Course Instructor	Location	
Lesson Lab Module #1	Day/Time	Page 1 of 2
<p>Topic</p> <ul style="list-style-type: none"> • Instructor and participant introductions • Laboratory and Simulator Course goals • Module goal • Lecture 	<p>Discussion/Slides/Notes</p> <ul style="list-style-type: none"> • Familiarization with Ship Service Fuel Cell (SSFC). <ul style="list-style-type: none"> • Start-up procedures. • Normal shutdown procedures. • Non-scheduled emergency shutdown procedures. • Maintenance and hazard potentials. • Course goals will be accomplished through: <ul style="list-style-type: none"> • Lecture. • Simulation. • Fuel cell lab bench-top workstation. • Familiarization with SSFC cell stack, Mechanical Balance of Plant, and Electrical Balance of Plant. <ul style="list-style-type: none"> • Preparatory steps necessary to bring SSFC from OFF MODE to HEAT MODE on raw fuel. • After discussion of steps, bring the simulator up to this point. 	<p>Supplemental Material</p> <ul style="list-style-type: none"> • Course Manual <ul style="list-style-type: none"> • Course Outline • Lecture Slides/Notes • Procedures Manual • Select Classroom Module slides • MBOP sub-system diagrams and component illustrations from FCE (13)

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Lab Module #1	Day/Time	Page 2 of 2
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Topic	Discussion/Slides/Notes	Supplemental Material
<ul style="list-style-type: none"> • Lecture (cont'd) 	<ul style="list-style-type: none"> • Processed Fuel System (PFS) <ul style="list-style-type: none"> • Start Burner System (SBS) • Nitrogen Purge System (NPS) • Instrument Air System (IAS) • ZnO Regeneration System (ZCS) <ul style="list-style-type: none"> • Electrical Balance of Plant (EBOP) • Electrical Control System (ECS) • Power Conditioning System (PCS) 	<ul style="list-style-type: none"> • Operator's Manual
<ul style="list-style-type: none"> • Review of Module #1 		

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Lab Module #2	Day/Time	Page 1 of 2
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Topic	Discussion/Slides/Notes	Supplemental Material
• Module Goals	<ul style="list-style-type: none"> • Discuss remaining stages to bring SSFC to normal power. • Bring simulator to full power. • Start discussion of normal shut down procedures. • Initiate normal shut down on simulator. 	<ul style="list-style-type: none"> • Operator's Manual
• SSFC Start-up Procedures	<ul style="list-style-type: none"> • OFF-MODE discussion - nitrogen blanket is maintained on the preformer unit and the cell anodes. • Introduce Six stages in the transition from OFF-MODE to HOT HOLD • Stage 1 discussion - confirmation of status and preparation of auxiliary systems • Stage 2 discussion - initial stack warming • Stage 3 discussion - fuel processing system heating 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13)
• Simulator is used to bring SSFC to Stage 3 operation	<ul style="list-style-type: none"> • Demonstration • Individual and group exercises 	<ul style="list-style-type: none"> • Simulator Manual

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Lab Module #2	Day/Time	Day/Time	Page 2 of 2
Topic	Discussion/Slides/Notes		Supplemental Material
• SSFC start-up procedure (cont'd)	<ul style="list-style-type: none"> • Stage Four discussion - Further heating of HDS, Prereformer, and Fuel Stacks. • Stage Five discussion - continuation of the heating process through HOT HOLD • Stage Six discussion - full fuel prereformer operation, final stack heating and transition to HOT STANDBY and finally transition to NORMAL POWER. 		<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13)
• Simulator is used to bring SSFC from Stage 3 to MORMAL POWER operation	<ul style="list-style-type: none"> • Demonstration • Individual and group exercises 		<ul style="list-style-type: none"> • Simulator Manual

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Lab Module #3	Day/Time	Page 1 of 2
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Topic	Discussion/Slides/Notes	Supplemental Material
• Module Goals	<ul style="list-style-type: none"> • Understand the principles and procedures to bring the SSFC from NORMAL POWER to SHUTDOWN. • Discuss Emergency Shutdown procedures 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13)
• Shutdown Procedures	<ul style="list-style-type: none"> • Preview of Startup procedures through NORMAL POWER • Discuss return to HOT STANDBY • Discuss return to HOT HOLD • Six Stages to Cold Shutdown 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13)
• Simulator is used to demonstrate cold shutdown from NORMAL POWER	<ul style="list-style-type: none"> • Demonstration • Individual and group exercises 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13) • Simulator Manual

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Lab Module #3	Day/Time	Page 2 of 2
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Topic	Discussion/Slides/Notes	Supplemental Material
• Emergency Shutdown	<ul style="list-style-type: none"> • Emergency shutdown overview • Initiating events for emergency shutdown 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13) • Simulator Manual
• Simulator is used to demonstrate emergency shutdown from NORMAL POWER	<ul style="list-style-type: none"> • Demonstration • Individual and group exercises 	

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Lab Module #4	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
• Module Goals	<ul style="list-style-type: none"> • SOP and EOP review and simulation • Startup, loading, and normal and emergency shutdown procedures • Use simulator extensively for operator experience and familiarity 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13) • Simulator Manual
• SOP and EOP review	<ul style="list-style-type: none"> • Review startup, loading, and normal and emergency shutdown processes and procedures in depth 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13) • Simulator Manual
• SOP and EOP simulation exercises	<ul style="list-style-type: none"> • Simulate various abnormal process states and contingencies and review their cause, effects, and operator corrective action • Simulate various emergency shutdown initiating events 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13) • Simulator Manual

Course _____
Instructor _____
Location _____
Date _____

Lesson Lab Module #6	Day/Time	Page of
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Topic	Discussion/Slides/Notes	Supplemental Material
• Bench top fuel cell workstation	<ul style="list-style-type: none"> • Introduce bench top fuel cell workstation • Discuss startup, operation, and shutdown procedures 	<ul style="list-style-type: none"> • Bench top fuel cell workstation manufacturer's manual
• Bench top fuel cell workstation operation	<ul style="list-style-type: none"> • Prepare and start up fuel cell • Monitor fuel cell operation, collect operating data • Shutdown fuel cell • Analyze operating data. 	<ul style="list-style-type: none"> • Bench top fuel cell workstation manufacturer's manual
• Lab and simulator course learning outcomes	<ul style="list-style-type: none"> • Discuss lab results and experience • Compare and contrast bench top fuel cell with SSFC 	

Course Instructor	Location	Date
Lesson Lab Module #5	Day/Time	Page 1 of 1
Topic	Discussion/Slides/Notes	Supplemental Material
• Module goal	<ul style="list-style-type: none"> • ZnO regeneration cycle • General maintenance procedures 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13) • Manufacturer data
• Simulate ZnO regeneration cycle on simulator	<ul style="list-style-type: none"> • Discuss ZnO regeneration cycle. • Simulator Demonstration • Individual and group simulator exercises 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13) • Simulator Manual
• Maintenance procedures	<ul style="list-style-type: none"> • MBOP and EBOP preventive maintenance and routine maintenance schedules and procedures • Custom maintenance requirements for fuel cell stack, catalysts beds, etc. 	<ul style="list-style-type: none"> • Operator's Manual • Maintenance check off and report forms

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Lab Module #6	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
• Module goal	<ul style="list-style-type: none"> • Bench top fuel cell workstation <ul style="list-style-type: none"> • Introduce bench top fuel cell workstation • Discuss startup, operation, and shutdown procedures 	<ul style="list-style-type: none"> • Bench top fuel cell workstation mfr's. manual
• Bench top fuel cell workstation operation	<ul style="list-style-type: none"> • Prepare and start up fuel cell • Monitor fuel cell operation, collect operating data • Shutdown fuel cell • Analyze operating data 	<ul style="list-style-type: none"> • Bench top fuel cell workstation mfr's. manual
• Lab and simulator course learning outcomes	<ul style="list-style-type: none"> • Discuss lab results and experience • Compare and contrast bench top fuel cell with SSFC operations 	

2.3 Shipboard Modules

The shipboard training modules provide comprehensive review and capstone experience in operating a Direct Fuel Cell Ship Service Fuel Cell (DFC SSFC) in real-time for future operators. The shipboard training modules would fill a 2- to 4- day hands-on lesson series (depending on length of training course) preparing the trainees to be operators of a DFC SSFC.

The shipboard training modules are presented in lesson board form. The reference numbers on supplemental materials lists refer to source listed numerically in the Reference page of this section.

Course Instructor	Location	
	Date	
Lesson Shipboard Module #1	Day/Time	Page 1 of 2
Topic	Discussion/Slides/Notes	Supplemental Material
• Introductions	<ul style="list-style-type: none"> • Introduce course overview and training modules 	<ul style="list-style-type: none"> • Operator's Manual
• Course goals	<ul style="list-style-type: none"> • DFC 600A MCFC SSSFC Systems Overview • DFC Systems • Personal Safety • Power Conditioning • Safe Operations • Control systems • Control Station Overview • Total System Overview • Operations Experience 	<ul style="list-style-type: none"> • Operator's Manual
• DFC 600A MCFC SSFC Systems Overview	<ul style="list-style-type: none"> • DFC Components • MBOP Components and Systems • EBOP Components and Systems • Backup systems & components • Emergency controls and actions • Emergency systems & actions 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13)

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Shipboard Module #1	Day/Time	Page 2 of 2
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Topic	Discussion/Slides/Notes	Supplemental Material
• Operations overview	<ul style="list-style-type: none"> • Review main components and systems • Review support system inputs • Review safety alerts and actions • Review controls and operation • Heat-Up Ramp Hold • Ramp-down to Reduced Load • Ramp-down to Hot Standby • Emergency Shut Down 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13)
• Exercise #1 - Ship system tours and demonstration system operation and shutdown	<ul style="list-style-type: none"> • Walk through of ship systems, SSFC in operation • Fuel handling, transfer, supply • Water storage, treatment, supply & transfer • Air handling, Control and service • Nitrogen purge • Line up components to MBOP • Monitoring systems and functions • Demonstrate shut down procedure to Hot Standby 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13)

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Shipboard Module #2	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
• DFC Components	<ul style="list-style-type: none"> • Stack components and systems <ul style="list-style-type: none"> • Inputs • Fuel • Air • Nitrogen • Anode Cover Gas • Recycle Loop • DC Power Out 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13)
• DFC Controls	<ul style="list-style-type: none"> • Controls - Local and Remote <ul style="list-style-type: none"> • Emergency control and action • Backup systems & components • Emergency systems & actions 	<ul style="list-style-type: none"> • Operator's Manual
• Exercise #2 - System start up preparations	<ul style="list-style-type: none"> • Review MBOP Operations procedures • Review safety alerts and actions • Review DFC + Turbine Operations • Line up MBOP, DFC, Recycle loops, turbine boost • Monitor functions • Conduct Safety test procedures • Shut down all units 	<ul style="list-style-type: none"> • Operator's Manual • System diagrams from FCE (13)

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Shipboard Module #3	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
• Power Conditioning Unit	<ul style="list-style-type: none"> • EBOP • DC Power DFC output • AC Power output • Ship's Main Bus • Load sharing & load shedding theory • Lead and follow theory • Heat output & reutilization • HVAC to unit 	<ul style="list-style-type: none"> • Shipboard SSF/C • Operator's Manual • System diagrams from FCE (13)
• Exercise #3	<ul style="list-style-type: none"> • Review components • Review MBOP Unit Operations procedures • Review DFC Unit + Turbine Operations Procedures • Review EBOP Unit Operations procedures • Line up MBOP • Line up Direct Fuel cell • Line up recycle loop • Line up Turbine boost • Line up EBOP unit • Ramp to Heat up mode • Monitor conditions, • Conduct safety test procedures • Shut down all units 	<ul style="list-style-type: none"> • Shipboard SSF/C • Operator's Manual • System diagrams from FCE (13)

Course Instructor	Location	Date	Lesson Shipboard Module #4	Day/Time	Page 1 of 1
Topic	Discussion/Slides/Notes				Supplemental Material
• Personal safety	<ul style="list-style-type: none"> • Personal Safety equipment <ul style="list-style-type: none"> • Hazards & appropriate equipment • Establish techniques - Lock out / Tag out • Inherent dangers <ul style="list-style-type: none"> • Temperature • Fire • Pressure • Inhalation • Asphyxiation • Noise • Frostbite & burns • Monitors & sensors & Safety <ul style="list-style-type: none"> • Gas Monitors • Thermal Sensors • Alarms • Extinguishing agents <ul style="list-style-type: none"> • Cooling • Purging 				<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13) • Personal safety equipment • Hazardous materials documentation
• SSFC Safe Operations	<ul style="list-style-type: none"> • Review safety hazards, alarms, and procedures • Review pre-startup procedures • Demonstrate start up to Hot Standby • Demonstrate Cold Shut Down • Focus on monitoring and controls 				<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13) • Personal safety devices • Hazardous materials documentation

Course _____
 Instructor _____
 Location _____
 Date _____

Lesson Shipboard Module #5	Day/Time	Page 1 of 1
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Topic	Discussion/Slides/Notes	Supplemental Material
• SSFC Maintenance	<ul style="list-style-type: none"> • Review preventive, routine, and custom maintenance procedures • Review and identify components • Review and identify monitoring systems, maintenance tools, record keeping systems 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13) • Maintenance tools, data loggers, and check off and report forms
• SSFC Controls Review	<ul style="list-style-type: none"> • Review local control and HMI • Review remote control – locations, switching protocols • Review off site monitoring and control 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13)
• SSFC Control Stations	<ul style="list-style-type: none"> • Local control station and HMI tours • Remote control station location and HMI tours • Review control switchover contingencies and protocols • Review emergency shut down nitrogen purge system 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13)

Course _____
Instructor _____
Location _____
Date _____

Lesson Shipboard Module #6 Day/Time _____

Page 1 of 1

Topic	Discussion/Slides/Notes	Supplemental Material
• Final SSFC review	<ul style="list-style-type: none">• Demonstrate ancillary system knowledge• Demonstrate Safety systems knowledge	<ul style="list-style-type: none">• Shipboard SSFC• Operator's Manual• System diagrams from FCE (13)
• Exercise #4 - Operator experience	<ul style="list-style-type: none">• Complete pre-startup procedures• Perform start up• Ramp power, connect to ship's bus• Operate - Meet variable load• Ramp Power down to Hot Standby• Cool down• Prepare for cold shut down• Ambient dormant mode....Out of Service	<ul style="list-style-type: none">• Shipboard SSFC• Operator's Manual• System diagrams from FCE (13)

Course _____	Location _____	
Instructor _____	Date _____	
Lecture Shipboard Module #7	Day/Time	
	Page 1 of 1	
Topic	Discussion/Slides/Notes	Supplemental Material
<ul style="list-style-type: none"> • Final SSFC review • Demonstrate ancillary system knowledge • Demonstrate Safety systems knowledge • 	<ul style="list-style-type: none"> • Demonstrate ancillary system knowledge • Demonstrate Safety systems knowledge • System diagrams from FCE (13) 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13)
<ul style="list-style-type: none"> • Exercise #4 – Operator experience 	<ul style="list-style-type: none"> • Complete pre-startup procedures • Perform start up • Ramp power, connect to ship's bus • Operate – Meet variable load • Ramp Power down to Hot Standby • Cool down • Prepare for cold shut down • Ambient dormant mode....Out of Service 	<ul style="list-style-type: none"> • Shipboard SSFC • Operator's Manual • System diagrams from FCE (13)

References

Operator Training Modules

1. Fuel Cell Technology Handbook, Gregor Hoogers, Ed., CRC Press2003.
2. Fuel Cell Handbook, 6th Edition, US DOE, Office of Fossil Energy, National Energy Technology Laboratory, 200.
3. Fuel Cell Training Seminar, NAVSEA Philadelphia, June 17, 1997, PowerPoint Presentation.
4. Distributed Electric Power Generation, Final Report, US Army Corps of Engineers, Energy Research and Development Center, 2003.
5. Application of Fuel Cells in Surface Ships, UK department of Trade and Industry Energy Group, Crown Publishers, 2001
6. Distributed Power Generation, Planning and Evaluation, Willis and Scott, Marcel Dekker, Inc., 2000.
7. www.fuelcells.org Fuel cell information portal
8. www.fce.com Fuel Cell Energy, Inc. homepage
9. Distributed Electric Power Generation, Summary of Alternative Available Technologies, Final Report, US Army Corps of Engineers, Energy Research and Development Center, 2003.
10. Fuel Cell Power Systems Performance Test Codes, ASME PTC 50-2002, ASME, 2002.
11. Marine Fuel Cell Market Analysis Final Report, USCG R&D Center, 1999
12. Comparative Life Cycle Costs of Fuel Cells and Other Propulsion Systems Final Report, 2000
13. See Appendix.
14. An Investigation of the Integration of Hydrogen Technology into Maritime Applications, R. W. Foster, DCH Technology, Inc., 2000.
15. Preliminary Screening of Candidate Vessels for At-Sea testing of a Molten Carbonate Fuel Cell Ship Service Generator Final Report, USCG R&D Center, 2001
16. Marine Applications of Fuel Cells, S. Allen, et al, Naval Engineers Journal, January 1998.
17. Roadmap to an Electric Naval Force, Naval Research Advisory Report, US Navy Research Advisory Committee, 2002.

Sample Bench Top Fuel Cell Workstation commercial sources

1. www.fuelcellstore.com
2. www.minihydrogen.com
3. www.anuvu.com

3.0 Learning Technology Recommendations

The curriculum design and delivery should make best use of available learning technologies. In anticipation of the delay from the preparation of this report and the first operator training curriculum offered, perhaps up to several years, research was performed to suggest the future state of the art of learning technologies to be considered and adopted for the operator training curriculum.

Several key areas were identified in areas including hardware, software and communications networks including the Internet. The impact and advantages of these technologies were considered in each of the classroom, lab and simulator, and shipboard training modules.

3.1 Classroom Modules

3.1.1 Hardware

The future of classroom learning activity will certainly include greater use of portable personal computers (PCs). For example, laptop PCs are required of each student at Maine Maritime Academy. The PCs are used in laboratories for data acquisition and display and analysis of lab findings. Nearly all classroom and lecture halls now have information technology (IT) suites from which instructors can bring their classroom presentation materials stored on their laptop PCs. Engineering lecture presentations routinely include Internet links to academic and commercial information containing multimedia presentations and animated models of various systems.

3.1.2 Software

The latest advance in software for course management – including classroom material development, storage, presentation, and distribution – is the campus-wide course management system such as provided by BlackBoard and other commercial vendors. These systems encourage and facilitate continuous communication between instructor and student through use of email, course announcements, course documents, classroom presentation links and sources, chat rooms for post-lecture or invited expert virtual discussions, assignment collection, on-line self-managed quizzing and grading, and other features. These systems increase learning and improve outcomes mainly through the increase and acceleration of the exchange and organization of information. All instructors at the Academy use course management software at some level in their classes.

3.1.3 Communications Networks

The classroom modules are designed to make best use of classroom and instructor hardware and software through advanced classroom embedded communications links. The future will see students bringing to lecture laptop or tablet PCs equipped with wireless communications devices enabling the student to not only link with web sites simultaneously with the instructor's presentation, but to link also with the instructor's PC. If the instructor and student are using tablet PCs, where hand-written notes can be added by electronic pen to pre-developed lecture materials, the student can both take his or her own notes but have immediate wireless access to the instructor's scripted file. The student leaves class with his or her own written notes plus the instructor's annotated notes, all in electronically stored files suitable for electronic editing and printing.

3.1.3.1 Sample Lesson

The author has experimented with tablet PC functions in lectures to evaluate some of the tablet PC advantages and highly recommends its use in the operator training modules. The Reference page in this section includes web sites and other resources that describe the functionalities and teaching advantages of the tablet PC.

The following is an example lesson using a tablet PC classroom instruction application. The lesson was an introduction to fuel cells in a senior-level course in distributed generation technologies in a TAC-ABET accredited BS degree program in Power Engineering Technology at MMA.

1. The author, as instructor, prepared an abbreviated outline of the lecture topics printed as a handout for students with space available to write down definitions and other details of lecture content and learning outcomes. The instructor prepared also outline drawings of a simple fuel cell with some annotation and detail left to be hand written by students in lecture.
2. The same two documents were stored as files on the tablet PC. The files were opened at the beginning of lecture and the tablet PC screen projected to the class via PC screen projector and screen. As the instructor lectured, he used the tablet PC stylus to hand write definitions, comments, and other information directly on the PC screen, visible to all students. The same method was used to annotate the fuel cell graphic with component labels, flow

directions, etc. Different colors and line qualities were used for clear communication.

3. Students remained active in the lecture as it was their responsibility to complete the information on the handout.
4. At the end of lecture, the instructor stored the files complete with hand written notations. The files were later posted for review or downloading by all students via the BlackBoard course management software.

3.1.4 Texts and Supplemental Materials

In each classroom module suggested readings are listed. These published texts, articles, and Internet web sites are considered to be the best resources at the time of this report. However, the recommended resources are subject to revision and even obsolescence as fuel cell technology in general, and Ship Service Fuel Cell (SSFC) technology specifically, change in time. Future course developers are cautioned to use the suggested classroom reading assignment resources as templates or founding resources only and to research again the most current publications at the time of curriculum development.

3.2 Laboratory and Training Simulator Modules

The laboratory and simulator modules of the course include a high-function SSFC teaching simulator and bench top fuel cell workstation for hands-on operator training in preparation for shipboard SSFC training.

3.2.1 Bench Top Fuel Cell Workstation

Many fuel cell demonstrator workstations are available. The workstations include fuel cells of various types, usually PEM type, with various sophistication of monitoring and data acquisition systems, and at widely varying cost. Commercial workstation availability and features are subject to change. No one workstation is recommended in this report. A selection at the time of this report is considered premature considering the delay until the curriculum finally is offered. More must be learned about operator skills challenges and learning needs, which will be determined with more experience operating a post-laboratory, advanced design SSFC. Current commercial vendors of fuel cell training systems and workstations are included in the reference section.

3.2.2 Training Simulator

This portion of the report details the initial requirements for a dynamic training simulator of the SSFC. The original formulae for a dynamic computer simulation model of a MCFC power plant were developed by John J. McMullen Associates, Inc., Alexandria, VA for the US Coast Guard. (See Dynamic Simulation of a Fuel Cell Powered Electric Drive Ship, Report No. CG-D-12-01, 2001).

Simulator engineers at Kongsberg Maritime Simulation in Horten, Norway were consulted to learn about the latest technology in dynamic simulation. Kongsberg Maritime is a world leader in dynamic ship bridge and engine room simulation. Kongsberg is currently working on new techniques to allow complete interaction between an instructor master work station and student work station. In addition they are currently working on software that would allow students to purchase a limited time frame license for a simulation program. The program would be installed on their computers and they would log into the master simulator computer and run the program remotely via an intranet. This level of hardware, software, and communications networks is recommended for the SSFC training simulator to provide the best learning outcomes and to maintain the technological currency of the simulator for as long as possible.

Experience with many marine training simulators – ship steam systems, ship auxiliary systems, navigation simulators, etc. – and the forward-looking consultations with Kongsberg personnel, provided background for the following training simulator minimum specifications. The dynamic simulation embedded in the training simulator must detail the start up, normal operating characteristics, and select emergency operation procedures for the SSFC. The following list suggests minimum requirements for a SSFC training simulator to be used in conjunction with an immersion operator training course:

- The computer configuration should be in a workstation environment, with each individual student station capable of acting as a stand alone trainer, or controlled through a master instructor station. Commercially available software such as NETUP™ can be used to allow communication, monitoring, and instructional displays between the instructor station and the student stations.
- The software simulation program can be developed using a variety of software tools such as SIMSMART™ dynamic simulation software and MATLAB™ analytical software.

- The program should be capable of simulating systems cold starts and shut downs in both real time and, because of the length of time for stack warm up, accelerated time.
- The program should be capable of monitoring the fuel cell stack and the balance of plant reaction (BOP) as loads are introduced to the fuel cell. When at operating capacity, the same consideration should be given to transient loads.
- The program should be capable of the introduction of faults some of which will put the unit in a hot stand-by condition. From hot stand-by the simulator should be capable of accepting loads when a fault is found and corrected.

The lecture portions of the laboratory and training simulator modules should include the hardware, software, and communications networks technologies also suggested for the classroom modules.

3.3 Shipboard Modules

Shipboard training modules, for the most part, comprise standard hands-on training and evaluation procedures common to many shipboard systems operator training curricula. The lecture portions of the shipboard modules should include the hardware, software, and communications networks technologies also suggested for the classroom modules.

References

Learning Technology

1. How to Do Everything on Your Tablet PC, Bill Mann, McGraw Hill, 2003.
2. icampus.mit.edu MIT research center for expanded use of technology in education
3. ABC's of e-Learning, Brooke Broadbent, Jossey-Bass, Inc. A Wiley, Company, 2002.
4. Teaching Essentials, Course Seminar, Dr. Jerry W. Samples, Teaching the Teacher, Inc., Johnstown, PA. 2003.
5. www.blackboard.com Course management software system.
6. www.webCT.com Course management software system.

4.0 Applicable Navy Training Standards Overview

The US Navy has been improving its standards for training progressively for many years, accelerating in more recent times as high-bandwidth communications and open-source learning technologies have made significant technical advances at lowering costs. The Navy is continuously changing its outcomes and direction for training as it attempts to determine training needs and available technology in the future.

These changes are embedded in new guides and standards for pedagogy, teaching materials, and learning technologies for task-based curriculum development. New guides and standards apply to distance or e-learning (e.g., satellite communications), reusable learning objects, multimedia instruction, and so forth across all learning methodologies.

The ship service fuel cell (SSFC) operating curriculum modules outlined in this report are designed for ready adoption to relevant Navy standards as outlined in current Navy documentation researched for this report. Further interfacing and collaboration with responsible Navy training personnel will result in a detailed Navy-approved curriculum meeting all guides and standards at the time of the curriculum offering.

The Reference list at the end of this section provides resource information directed toward relevant Navy training documentation.

References

Applicable Navy Training Standards Overview

1. MIL-HDBK-29612-1A through 29612-5, Department Of Defense Handbook Guidance For Acquisition Of Training Data Products And Services, 2001
2. NAVEDTRA 130A Vol I through III, Task Based Curriculum Development Manual, 1997
3. www.npdc.navy.mil, Navy Personnel Development Center.
4. www.navylearning.com Navy training resources portal
5. www.cnet.navy.mil Naval Education and Training Command web site
6. www.navylearning.navy.mil SCORM 1.2 SUPPORT GUIDE for the NAVY Integrated Learning Environment

5.0 Interface with University of Maine Engineering-based Course

The laboratory, training simulator and shipboard modules include valuable and relevant content to augment the University of Maine (UMaine) Fuel Cell Engineering Curriculum developed in parallel with the report under a separate Office of Naval Research grant. The facilities at Maine Maritime Academy (MMA) will provide to the engineering course content involving expertise and information in the area of marine fuel cell power plant engineering.

Lecture topics and exercises from the operator training modules will be selected to augment the UMaine course, on the basis of learning outcomes requirements and preparation level of the engineering curriculum students. The MMA portion of the course is anticipated to include a one- or two-day immersion experience.

6.0 Summary

This report describes the results of tasks completed by Maine Maritime Academy engineering and marine transportation faculty to investigate and develop stationary and ship service fuel cell (SSFC) power plant coursework for United States Navy operators, engineers, and marine integrators, under Office of Naval Research grant number N00014-03-1-0240. This work has been performed within a broad multi-year program (BIW Marine Fuel Cell Verification-Trainer proposal to ONR, 21 August 2002) to confirm the viability of fuel cell based marine power plants through the operation and monitoring of equipment ashore and at-sea.

The report provides detailed lesson boards of comprehensive modules for classroom, laboratory, training simulator, and shipboard training areas. The modules include suggested topics, content, and supplemental learning materials. Recommended instructor resources and references for module presentations and exercises are provided for each training area. Research results into emerging learning technologies, in the forms of recommended hardware, software, communications networks, supplemental materials, and simulator specifications are reported with recommendations and reference sources.

The report includes description of the application of operator training module content in support of an engineering course in fuel cell power plants at the University of Maine developed under parallel separate proposal. Sources of information to configure and deliver the operator training curriculum in accord with Navy training content guidelines and standards are provided.

With the anticipation that up to several years' delay will occur between the time of this report and the maturity of the SSFC technology and its plant operations, suggestions for use of the information in this report and steps toward future curriculum development are provided throughout.

The resource documents recommended in this report, especially those listed in the Appendix are *design* documents subject to change with the evolution, maturity, and operator experience of the SSFC. Future instructors are reminded to seek the latest design production, and field documentation to gather training background for an operator training curriculum. The references in this report provide the future instructor with samples of documents he or she will be using to develop up-to-date content and supplemental materials in classroom, lab, and shipboard training.

7.0 References

The following recommended references provide instruction background and supporting information on the many aspects of the operator training curriculum content, in addition to the Supplemental Materials references provided at the end of the Operator Training Module section.

Training Modules

1. Codes and Standards for Marine Fuel Cells, Amann, J., and C. Artze. Trans. 2001.
2. Application of Fuel Cells in Surface Ships, Bourne, C., 2001.
3. Fuel Cells and How They Will Impact on Warship Design, Greig, A., and M. Boyes, 2001).
4. Marine Fuel Cell Market Analysis, Karin, Zvi, and N. Lewis, 1999.
5. Marine Molten Carbonate Fuel Cell Demonstration Module-USCGC Vindicator Ship Interface Studies, Karni, Zvi, and Peter Fontneau, 1999.
6. Dynamic Simulation of a Fuel Cell-Powered Electric-Drive Ship, Karni, Z., and H. Ghezel, 2001.
7. Fuel Cell Initiatives and Future Applications in the US Navy and US Marine Corps, Richard Carlin, 2nd Solid State Energy Conversion Alliance Workshop, Arlington, VA, 2003.
8. An Undergraduate Research Experience in New Technology Commercialization in PEM Fuel Cells, D. Ramers, ASEE Annual Conference and Exposition, Montreal, 2002.
9. Mobile Simulator Training, Alabama Power Company, Miller Electric Generating Plant, 1993. Document on file at Maine Maritime Academy.
10. Hydrogen Fuel Cell Engines and Related Technologies, Hydrogen Fuel Cell Maintenance Training Course, College of the Desert, Energy Technology Training Center, Palm Desert, CA, 2001.
11. www.fuelcellenergy.com FuelCell Energy web site.
12. www.fuelcelltechnologies.ca Fuel Cell Technologies, Ltd.
13. www.dodfuelcell.com Department of Defense
14. www.nfcrc.uci.edu National Fuel Cell Research Center
15. www.fuelcells.org Fuel Cell 2000, online newsletter
16. www.ornl.gov Oak Ridge National Labs
17. www.sandia.gov Sandia National Labs
18. www.ballard.com Ballard Power Systems
19. www.ercc.com Energy Research Corporation
20. www.fuelcell.com ElectroChem, Inc.

Appendix

Sample FCE Documents for SSFC Operator Training Curriculum

Table A1 provides a list of sample preliminary sources – mostly interim FCE design documents – having critical format, text, and diagrammatic information for training module supplemental material and Operator's Manual content. These sample documents are *dated information*, generally, and probably not current at the detail level. The source list is not comprehensive as many systems and procedures are yet to be detailed from final systems designs and configurations and operations experience. However, the future training course instructors will benefit from this list as it provides at least direction toward practical, effective training module and manual content source documentation.

Table A1 – Sample Source FCE Documents for training Module Content

Appendix Number	Topic and Description	Training Module
A1	SSFC DC Fuel Cell Stack Module – Stack Construction and assembly in PowerPoint format	Classroom #5 Lab #1 Shipboard #1, 2
A2	SSFC Process Unit (Normal Operation)	Classroom #5 Lab #1 Shipboard #1, 2
A3	DC Module – text description	Classroom #5 Lab #1 Shipboard #2
A4	SSFC Subsystems – Ten subsystem diagrams in PowerPoint format	Classroom #5 Lab #1 Shipboard#2
A5	SSFC Interface requirements summary	Classroom #5 Lab #1 Shipboard #1
A6	Mechanical Balance of Power – Final assembly drawings	Classroom #5 Lab #1 Shipboard #1
A7	Electrical Balance of Plant – One-line diagrams	Classroom #5 Lab #1 Shipboard#1,2
A8	SSFC EBOP – Wiring diagrams	Classroom #5 Lab #1 Shipboard # 1, 2

Appendix (cont'd)**Table A1 - Sample Source FCE Documents for training Module Content
(cont'd)**

A9	SSFC Power Conditioning System - Schematics	Classroom #5 Lab #1 Shipboard #3
A10	Control point and component labels	Classroom #5 Shipboard #1
A11	Operating state transitions diagram	Classroom # Lab #2 Shipboard #1
A12	Steady State Material Balance Summary	Classroom #5 Lab #2 Shipboard #1
A13	Start-up procedures	Classroom #5 Lab #5
A14	Analysis of ZnO Regeneration Sequence	Lab #5
A15	SSFC Special Safety Features	Classroom #5 Ship #1, 4
A16	Fire suppression - system description	Classroom #5 Shipboard #1, 4
A17	Combustible Gas Monitoring in the SSFC	Shipboard #4
A18	Hazard and Operability Study	Classroom #5 Shipboard #4
A19	FCE Inspection Guide and Checklist - Maintenance logging and reporting document	Classroom #6 Lab #5 Shipboard #5
A20	Maintenance and spare parts list	Lab #5 Shipboard #5

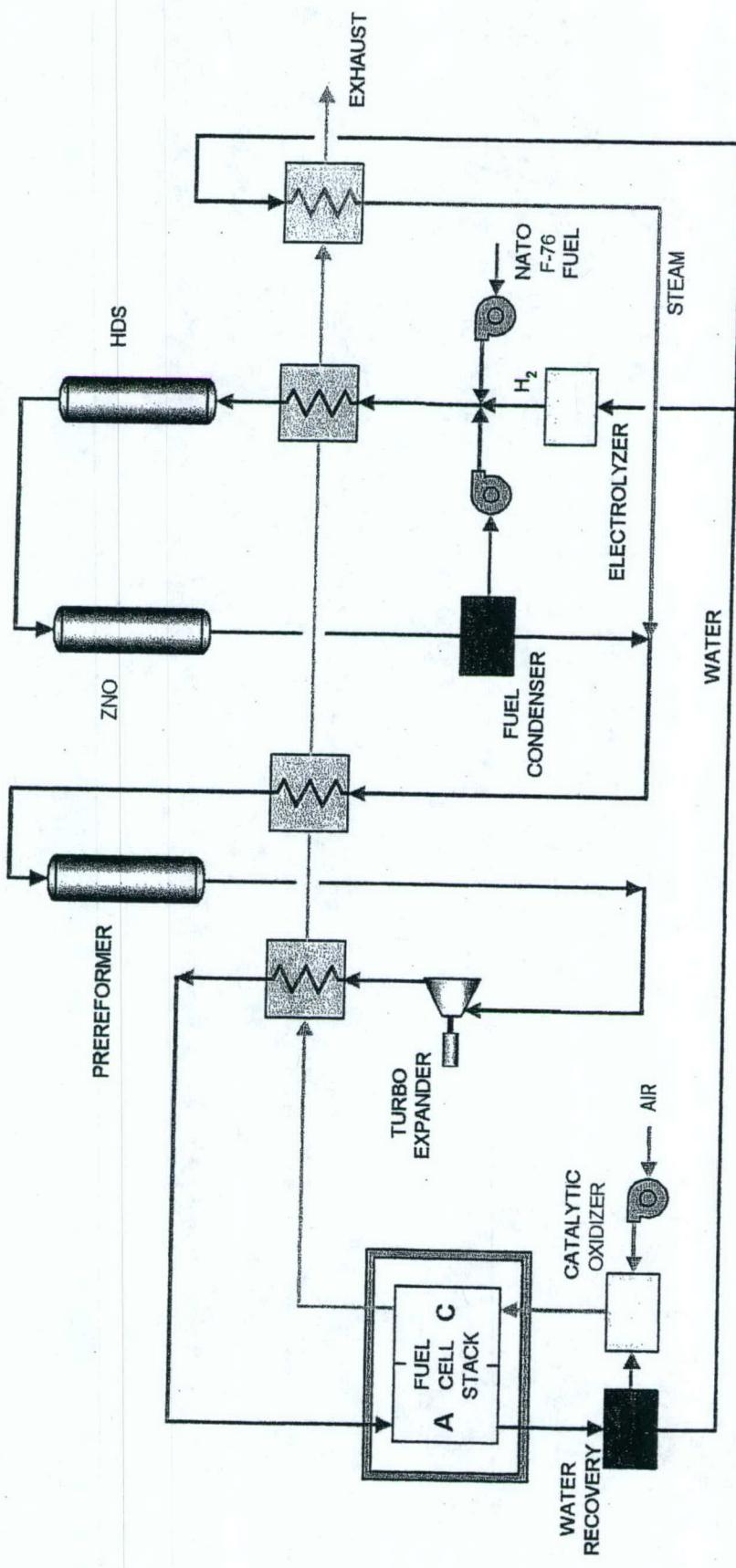
Appendix Number	Topic and Description	Training Module
A1	SSFC DC Fuel Cell Stack Module - Stack Construction and Assembly in PowerPoint format	Classroom #5 Lab #1 Shipboard #1, 2

Note: The detailed documents referenced in Appendix A1 contain manufacturer or manufacturer's supplier proprietary or company confidential information **not** available for public unclassified distribution, and have been deleted from this report.

Appendix Number		Training Module
A2	SSFC Process Unit (Normal Operation)	Classroom #5 Lab #1 Shipboard #1, 2

Note: The detailed documents referenced in Appendix A2 contain manufacturer or manufacturer's supplier proprietary or company confidential information **not** available for public unclassified distribution, and have been deleted from this report. The reference document included here provides a top level only process flow diagram schematic.

SSFC PROCESS SCHEMATIC



Appendix Number		Training Module
A3	DC Module - text description	Classroom #5 Lab #1 Shipboard #2

DC Stack Module

The DFC fuel cell stacks are based on FCE's commercial direct carbonate fuel cell technology that uses both direct (DIR, within the cell) and indirect (IIR, within the stack) internal reforming. The 625 kW SSFC module consists of two stacks, where each stack contains 354 cells and generates 335 kW DC. Each stack has an anode inlet and anode exhaust as well as a cathode inlet and cathode exhaust. Although anode gases are fed in parallel with piping and manifolding, cathode gases are fed in a series arrangement from one stack to the other, within an insulated enclosure, where the stacks are located. This enclosure, or "stack enclosure," provides an atmosphere of cathode gas at a temperature of 1100°F. Internal operating temperatures of the fuel cell stacks can be as high as 1200°F.

Processed fuel gas exits Heater E-101 at ~ 950°F before entering the hotbox. The fuel stream is then split between the two stacks, DFC-101A and DFC-101B. Fuel enters the anode inlet manifolds of each stack and is utilized in the fuel cell reactions. Steam and carbon dioxide produced by the fuel cell reaction along with unutilized fuel are routed from each anode exhaust manifold to a common pipe and exit the stack module.

The cathode inlet stream from Catalytic Oxidizer H-101 enters the hotbox at ~1100°F and is fed to the cathode inlet manifold of DFC-101A. The cathode exhaust from DFC-101A flows directly into the hotbox. Preheated air is also piped into the hotbox to control the enclosure temperature to a specified set point. This air stream is split off from the main process air stream after the air preheater E-104 and is controlled through valve TV-1501. Both the cathode exhaust from DFC-101A and the air stream then flow into the cathode inlet of DCF-101B. The exhaust from DFC-101B is piped from the cathode exhaust manifold out of the hotbox and to E-101.

The stacks are designed such that the positive end is at ground potential. At 100% rated power, each stack produces ~1260 amps at 265 Volts, DC. A positive and negative bus bar from each stack exits the hotbox and carries the current to the inverter section of the power conditioning system.

Appendix Number	Topic and Description	Training Module
A4	SSFC Subsystems - Ten subsystem diagrams in PowerPoint format	Classroom #5 Lab #1 Shipboard#2

Note: The detailed documents referenced in Appendix A4 contain manufacturer or manufacturer's supplier proprietary or company confidential information not available for public unclassified distribution, and have been deleted from this report.

Appendix Number		Training Module
A5	SSFC Interface requirements summary	Classroom #5 Lab #1 Shipboard #1

2.4 INTERFACE REQUIREMENTS

This section of the design description addresses the process and physical interfaces and support system requirements for the SSFC power plant demonstrator.

2.4.1 PROCESS AND PHYSICAL INTERFACES

The process and physical interfaces with the overall power plant are shown in Figure 2.4.1-1. The power plant consists of the main power plant module, which includes the EBOP, MBOP and the fuel cell stacks in their insulated enclosure, and the off module equipment. The off module equipment as shown in the figure includes: the circuit breaker enclosure, CB-1, the water treatment DI assembly, WT-102, the freshwater/seawater heat exchanger, E-112, the fire suppression system and the air intake filter F-101. The interfaces with the overall power plant are summarized in Table 2.4.1-1. Interface connections between the main module of the power plant and the off module subassemblies are summarized in Table 2.4.1-2.

Figure 2.4.1-1 SSFC DEMONSTRATOR INTERFACES

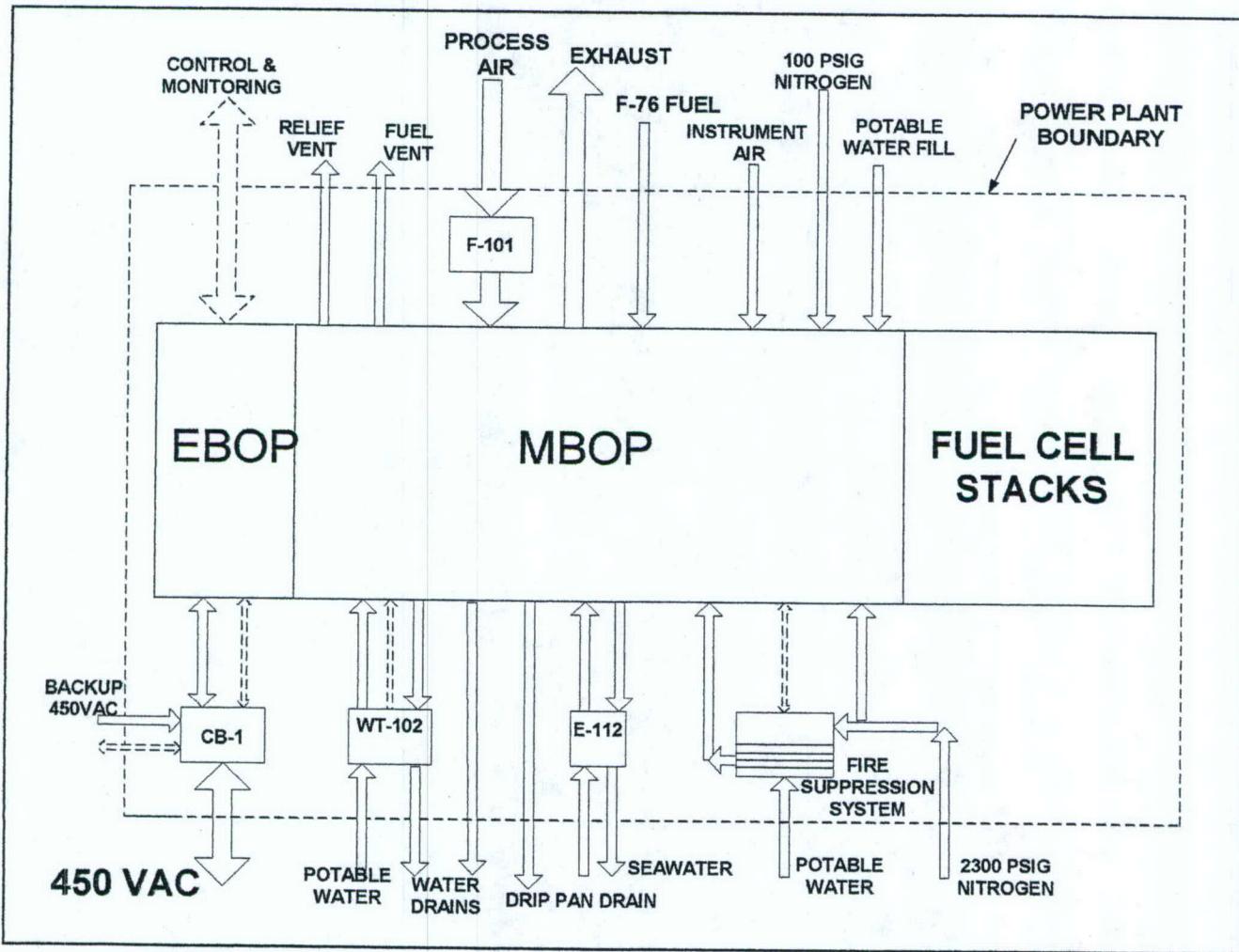


Table 2.4.1-1 OVERALL POWER PLANT INTERFACES

ELECTRICAL	Process	Size	Type
Output	3 Phase, 3 wire, 450 volts, 60Hz, 625 kW	1000 Amp	600 Volt Lug Connector
Input for start-up	3 Phase, 3 wire, 450 volts, 60Hz, <125 kW	200 Amp	600 Volt Lug Connector
Remote Control & Monitoring	Number TBD	TBD	Multi Pin Connectors
MECHANICAL			
F-76 Fuel supply	0.55 gpm @ 70 psig	1/2"	Swagelok
Air intake to salt air filter	2500 SCFM		
Process exhaust to exhaust stack	3100 SCFM @ 6 iwc	12"	150# drill pattern
Seawater for cooling	200 gpm@ 85°F	3"	150# RF Flange
Seawater return	200 gpm@ 104°F	3"	150# RF Flange
Instrument Air for pneumatic controls & atomization	100 psig	1"	Swagelok
Nitrogen for start fill and purge	100 psig	1/2"	Swagelok
Nitrogen for fire suppression	2300 psig	1"	Flange
Potable water fill	2 psig (Minimum)	1/2"	Swagelok
Potable water for fire suppression	125 psig	1"	Swagelok
Potable water for DI flush	120 psig	3/4"	Swagelok
Overflow Water drain	12 iwc	1"	Swagelok
Relief vent (to safe location)	< 5 iwc	3"	Flange
Fuel vent (to safe location)	< 5 iwc	2"	Flange
Drip pan drain (water or oily waste)	<10 iwc	3/4"	Swagelok

Table 2.4.1-2 INTERFACES BETWEEN MODULE AND OFF MODULE SUBASSEMBLIES

INTERFACES BETWEEN EBOP AND CB-1			
	Process	Size	Type
Output and Input for start-up	3 Phase, 3 wire, 450 volts, 60Hz, 625 kW	1000 Amp	600 Volt Lug Connector
Control & Monitoring	Number TBD	TBD	Multi Pin Connectors
INTERFACES BETWEEN MBOP AND SALT AIR FILTER F-101			
Process air	2500 SCFM	10"	150# drill pattern
INTERFACES BETWEEN MBOP AND HEAT EXCHANGER E-112			
Seawater for cooling	200 gpm@ 85°F	3"	150# RF Flange
Seawater return	200 gpm@ 104°F	3"	150# RF Flange
INTERFACES BETWEEN MBOP AND WATER TREATMENT DI ASSEMBLY			
Water to DI subassembly	2 gpm @ 50psig	3/4"	150# RF Flange
Water from DI subassembly	2gpm @30 psig	3/4"	150# RF Flange
Monitoring	Number TBD	TBD	Multi Pin Connectors
INTERFACES BETWEEN MBOP AND FIRE SUPPRESSION ASSEMBLY			
Nitrogen for fire suppression	125 psig	1"	Swagelok
Potable water for fire suppression	125 psig	1"	Swagelok
Control & Monitoring	Number TBD	TBD	Multi Pin Connectors

2.4.2 SUPPORT SYSTEM REQUIREMENTS

The SSFC power plant requires the following support systems: fuel, Nitrogen, seawater cooling, instrument air, potable water, over flow water and drip pan drain management, vent gas management and backup power. The following is an outline of requirements for each support system.

2.4.2.1 Fuel System

Fuel delivery at a minimum pressure of 70 psig is required. A fuel pressure up to 100 psig is acceptable. The maximum flow rate requirement is 0.6 gpm. The power plant can accommodate fuel distillate fuel such as F-76 with up to 1% sulfur by weight. Trace water and chlorides are acceptable. Water is accommodated in the process. Chlorides are removed in a guard section of the HDS reactor R-101.

2.4.2.2 Nitrogen

Nitrogen is used in the SSFC power plant to avoid uncontrolled fuel/air mixtures in the interest of safety and to protect the fuel cells and reactor catalysts from oxidation. A nitrogen purity of 99.5% is acceptable. Nitrogen is recirculated through the fuel processing systems and fuel cells during startup heating and controlled cooldown. Nitrogen is also used for purging fuel from the system in the event of emergency conditions as well as normal shutdown. Specific uses of nitrogen are summarized in Table 2.4.2.2-1, which details conditions for both intermittent and continuous use of nitrogen. The estimates are based on the assumption of a normal shutdown at 6 month intervals and a conservative assumption of one emergency shutdown each month. Nitrogen for ZnO regeneration cycles is conservatively based on a cycle every 24 hours which is the worst case related to operation at rated power with 1% sulfur fuel. Based on this evaluation of nitrogen requirements storage of nitrogen in standard 7 ft³ cylinders at 3000 psig is recommended. For initial demonstration, a facility with 8 to 10 cylinders connected to a common header and pressure transmitter, which forwards pressure level to the power plant. When the pressure is reduced to a prescribed level a signal for refill is actuated. In the event that the pressure falls below a prescribed level indicating future insufficiency for normal or emergency shutdown, or fire suppression, a power plant shutdown is initiated.

2.4.2.3 Seawater Cooling

The seawater cooling system requires 200 gpm of seawater delivered to the power plant heat exchanger E-112 at up to 25 psig and a maximum of 85°F. Seawater pressure loss through E-112 is 5 psi. At seawater temperatures above 85°F the power plant must operate at reduced power to avoid overheating certain parts of the power plant which are water cooled such as the power conditioning system.

2.4.2.4 Instrument Air

Instrument air, at 100 psig, is required by the power plant for pneumatic valve actuators. There are 31 control valves and 79 shutoff valves with pneumatic actuators. The instrument air must be dry (-40F dewpoint) and oil free. The continuous use rate is estimated at 19 SCFM and the peak rate is estimated at 61 SCFM.

Instrument air is also used for atomizing the diesel fuel in the start burner during power plant startup, shutdown and low power operation when the start burner is used for supplementary thermal management. The flow of atomizing air is 2.7 scfm. There is no requirement for this air to be dried or oil free.

2.4.2.5 Potable water

Under normal power operation the SSFC power plant is self sustaining in its water needs. During operation the power plant recovers up to 2 gpm from the fuel cells and conditions this water for use in the power plant process. Potable water is needed by the power plant under the following power plant conditions.

- a) After replacement of a demineralizer, WT-102, flushing of the replacement unit is conducted to ensure water resistivity of 1 megohm. The extra 2 gpm water for flushing exceeds the normal flow capability of the power plant water system. For this reason 2 gpm of potable water is required at the WT-102 for replacement demineralizer conditioning.
- b) Potable water to fill the condensate tank S-101 on initial power plant startup.
- c) Potable water to the coolant system for fill and makeup during operation in the event of minor leakage.
- d) Potable water to the condensate tank during low power level operation when recovered water is slightly less than the process requirement. The flow needed during low power operation is less than 0.1 gpm.
- e) Potable water to fill the tank V-108 in the water fogging fire suppression system.

2.4.2.6 Water overflow drain

Water is recovered in the power plant by condensing water formed in the electrochemical fuel cell process. During certain operating conditions excess water is recovered beyond the amount needed by the power plant process. The excess condensate collected in separator tank S-101 overflows to gravity drain. Provision is needed at the MBOP interface to manage this overflow gravity drain. This water has the following impurities.

2.4.2.7 Drip Pan Drain Management

A drip pan is located at the bottom of the MBOP enclosure. The purpose is to collect liquids, which may leak from the power plant systems. Liquids in the MBOP include: condensate water, demineralized water, coolant water, F-76 distillate fuel, and desulfurized distillate fuel.

The MBOP enclosure internal environment is at a sub atmospheric pressure of up to 6 iwc.

The drip pan has provisions to flow the collected drippings by gravity to a drain interface at bottom, of the enclosure on one side. Provision is needed to drain this oily waste liquid away from the powerplant. The drain must include provisions to prevent air from flowing into the subatmospheric module if no liquids are present.

2.4.2.8 Vent Gas Management

There are two gas vents from the MBOP which must be directed to a safe location without creating a back pressure in excess of 5 iwc. One gas vent is the 3" relief vent header, which collects gases from various parts of the power plant system. This vent can contain hydrogen, vaporized diesel fuel, desulfurized diesel fuel, or processed fuel with methane CO as well as hydrogen. The highest temperature of gases flowing from the vent header is 900°F. Under non relief conditions this vent will have a small flow of nitrogen to avoid the presence of air in the vent header.

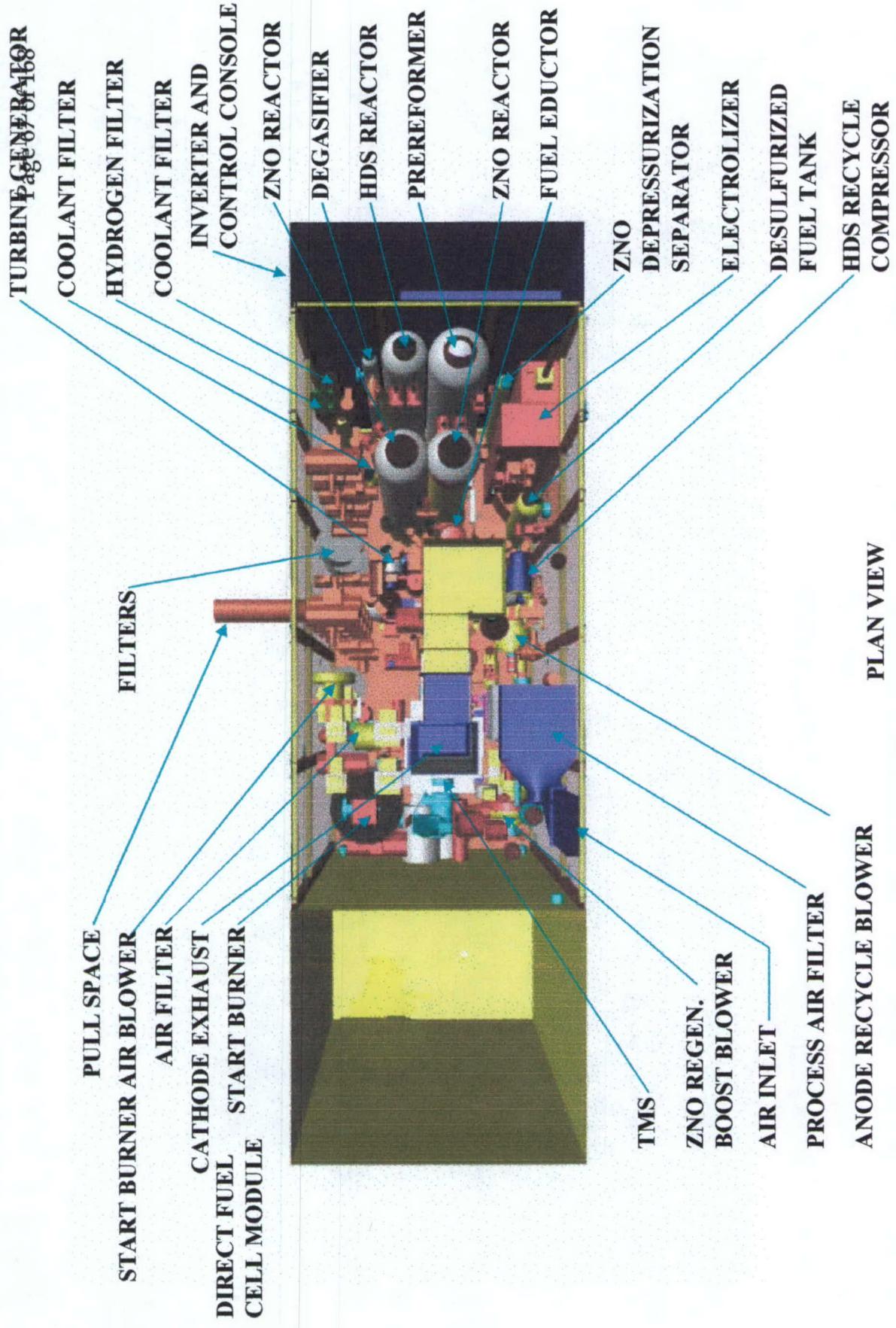
The other vent is the 2" fuel vent, which relieves gas from the fuel cell anodes to avoid an excessive pressure in the fuel cell stacks. The vent gas is processed fuel with hydrogen, methane and CO at a temperature of up to 1200°F.

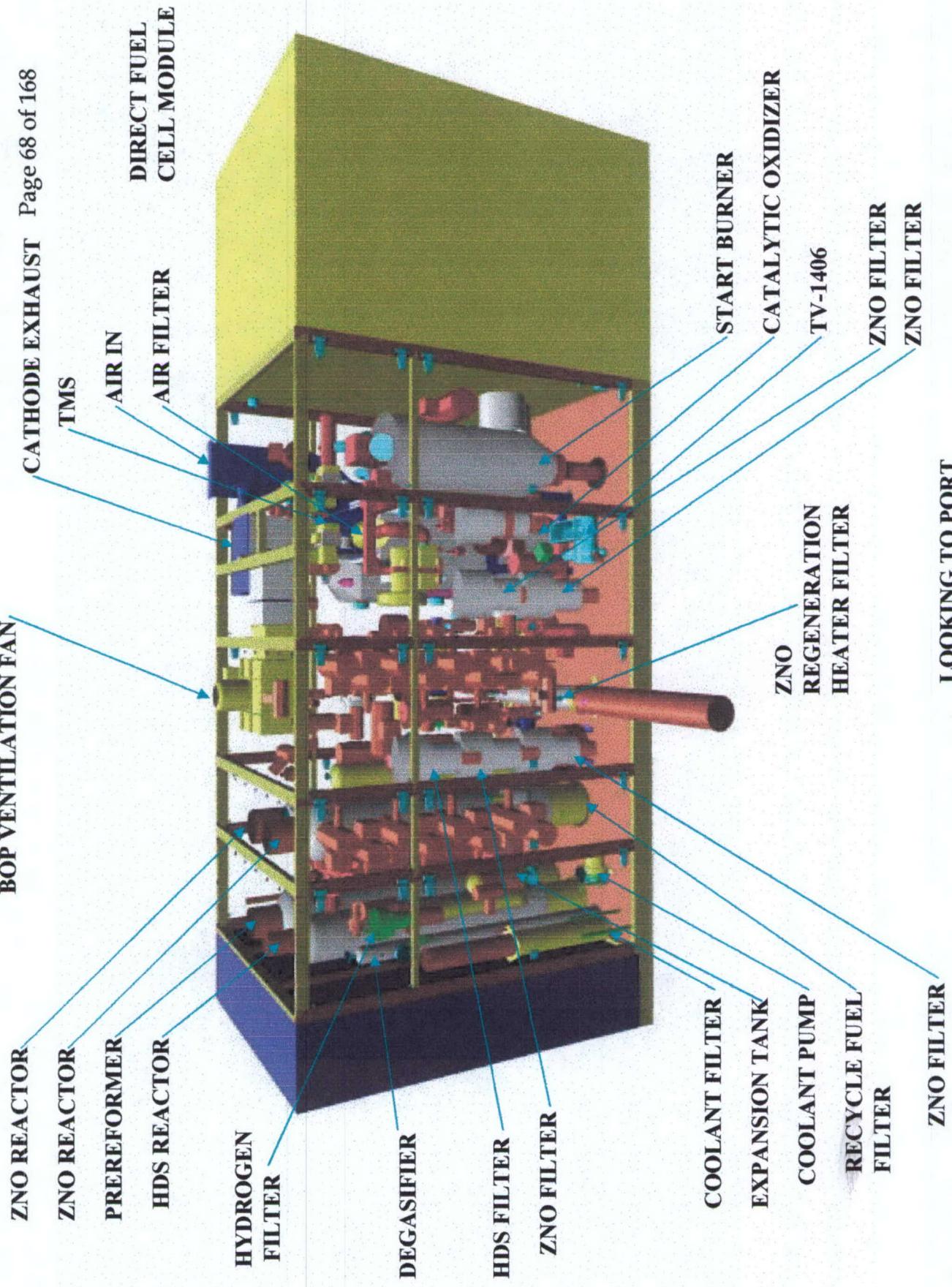
2.4.2.9 Backup Power

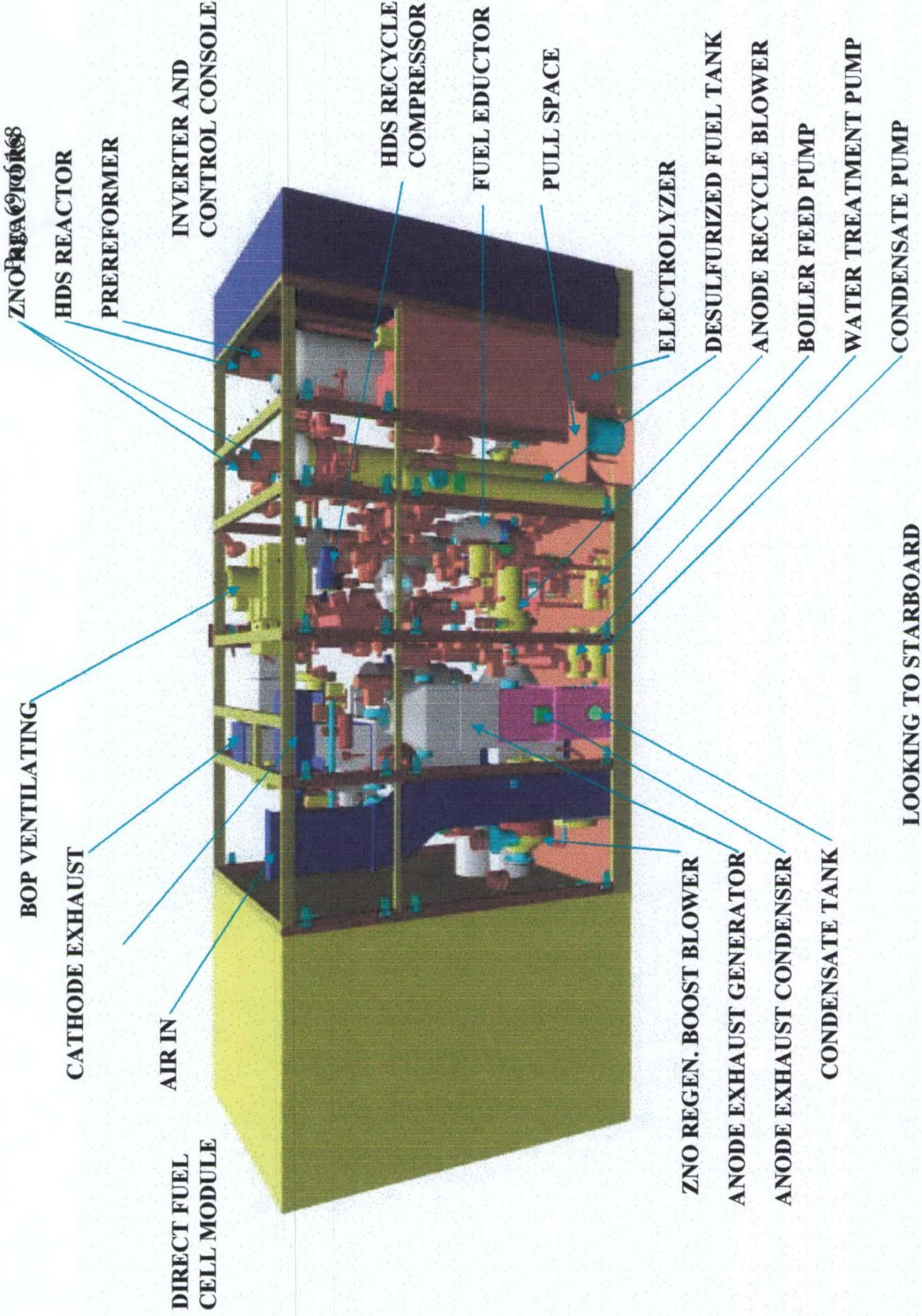
In the event that the normal source of auxiliary power to the power plant is lost, an emergency shutdown of the power plant is initiated. A backup power supply is needed during this type of shutdown to power the 4 hp coolant pump, P-104, the 5 hp MBOP vent fan B-104, and the 60 watt electrolyzer cabinet vent fan B-107. This equipment requires power during an emergency shutdown to maintain ventilation of the MBOP enclosure and to avoid combustible gases accumulating in the electrolyzer enclosure. Switchover of these items occurs automatically in the auxiliary power circuitry. The power circuit schematic is drwg #2609 "Emergency Backup Power Schematic" and is presented in PDF file 2609. The backup power supply receives a start signal from the power plant controller which is on the power plant UPS.

The requirement for the backup power supply is continuous operation with an output of about 10 kW for a period of about 48 hours while the power plant cools by natural losses or the normal auxiliary power supply is restored.

Appendix Number	Topic and Description	Training Module
A6	Mechanical Balance of Power - Final assembly drawings	Classroom #5 Lab #1 Shipboard #1

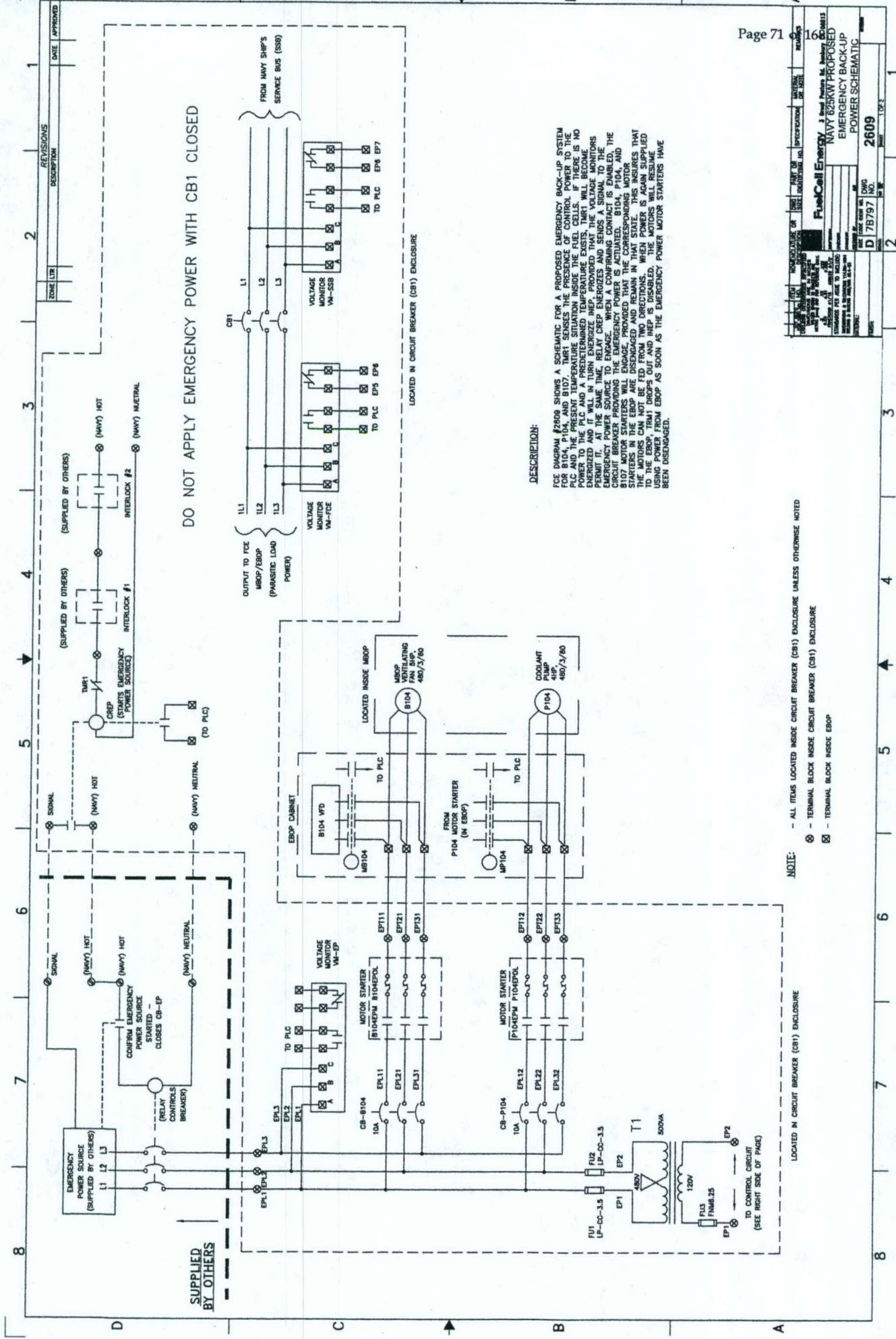


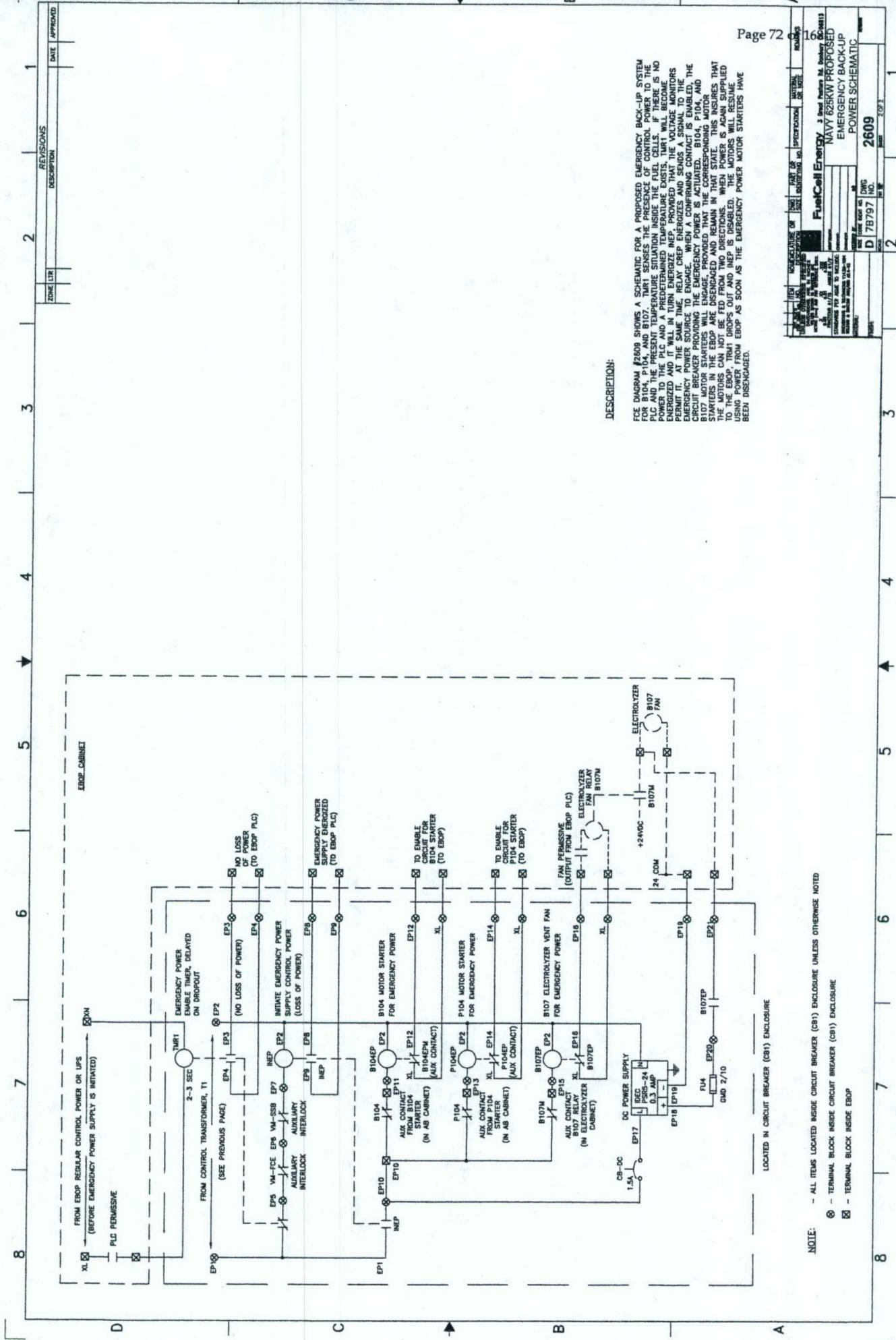




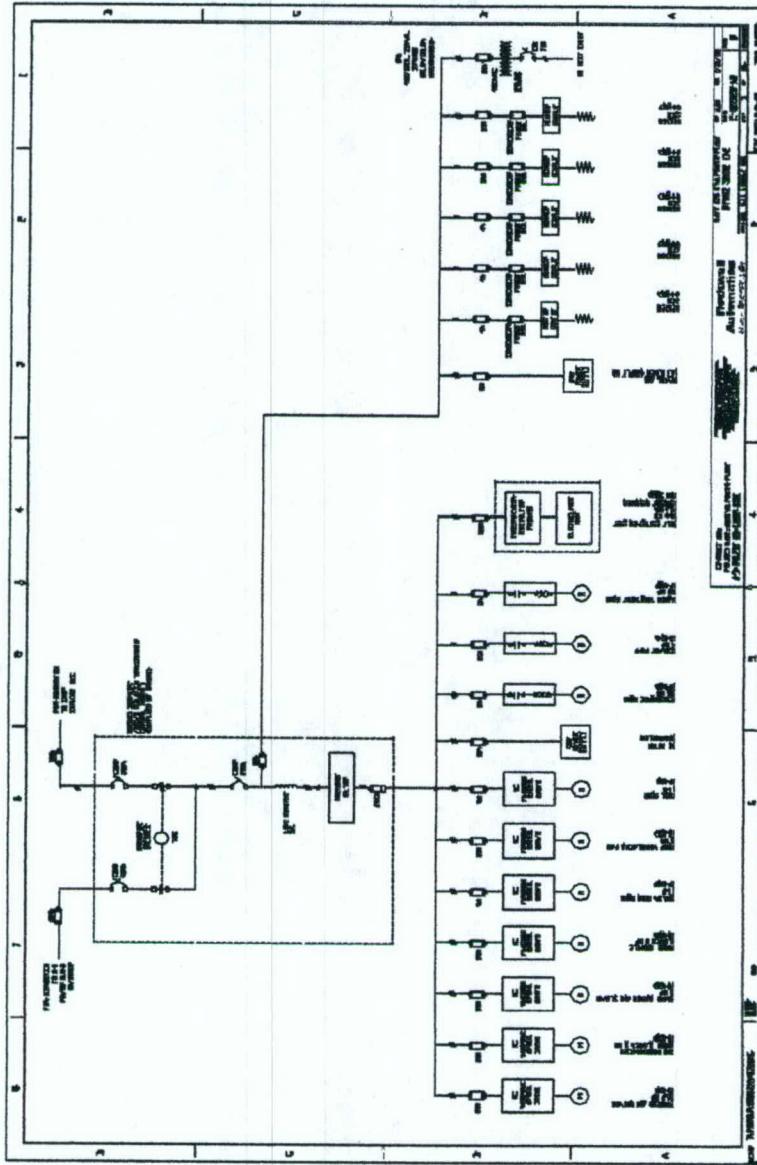
LOOKING TO STARBOARD

Appendix Number	Topic and Description	Training Module
A7	Electrical Balance of Plant - One-line diagrams	Classroom #5 Lab #1 Shipboard#1,2





Appendix Number		Training Module
A8	SSFC EBOP - Wiring diagrams	Classroom #5 Lab #1 Shipboard # 1, 2



Appendix Number		Training Module
A9	SSFC Power Conditioning System - Schematics	Classroom #5 Lab #1 Shipboard #3

SSFC

Power Conditioning System

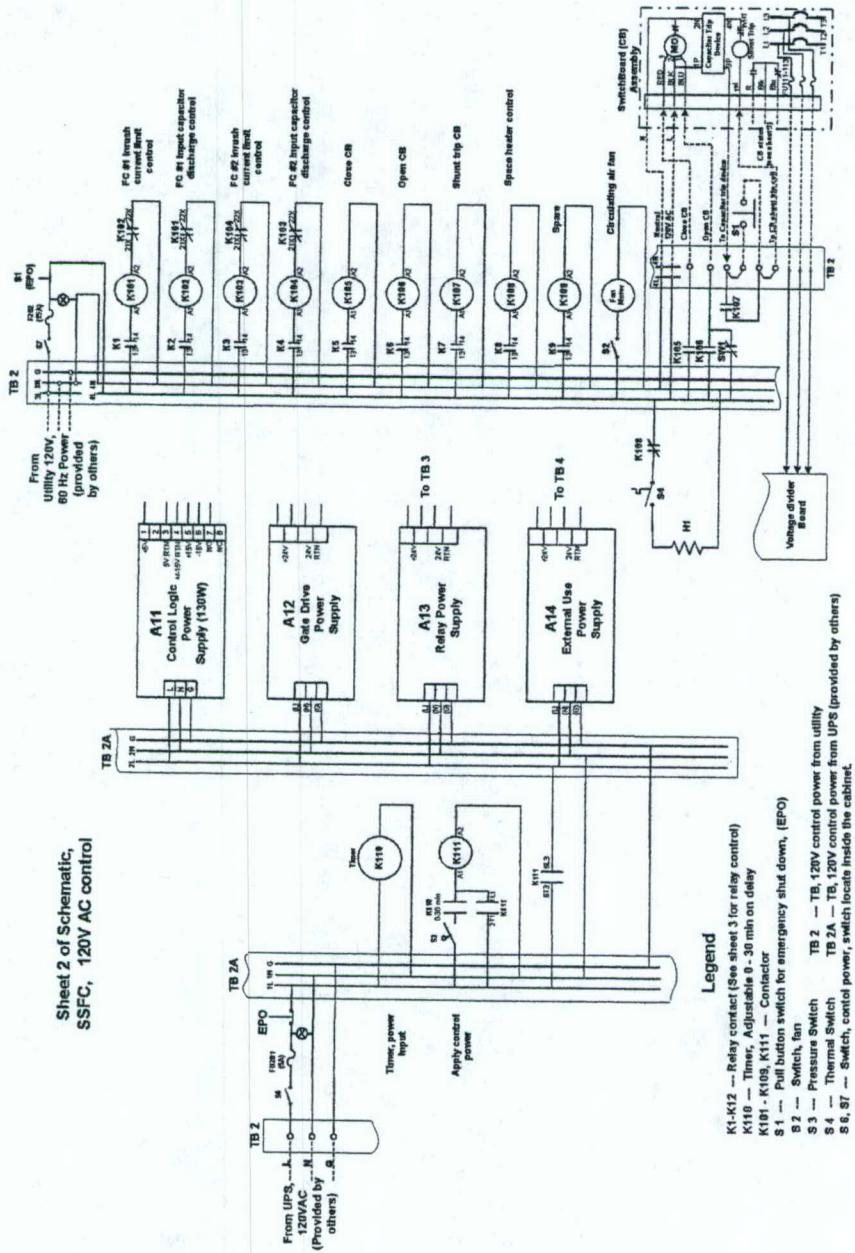
Schematics

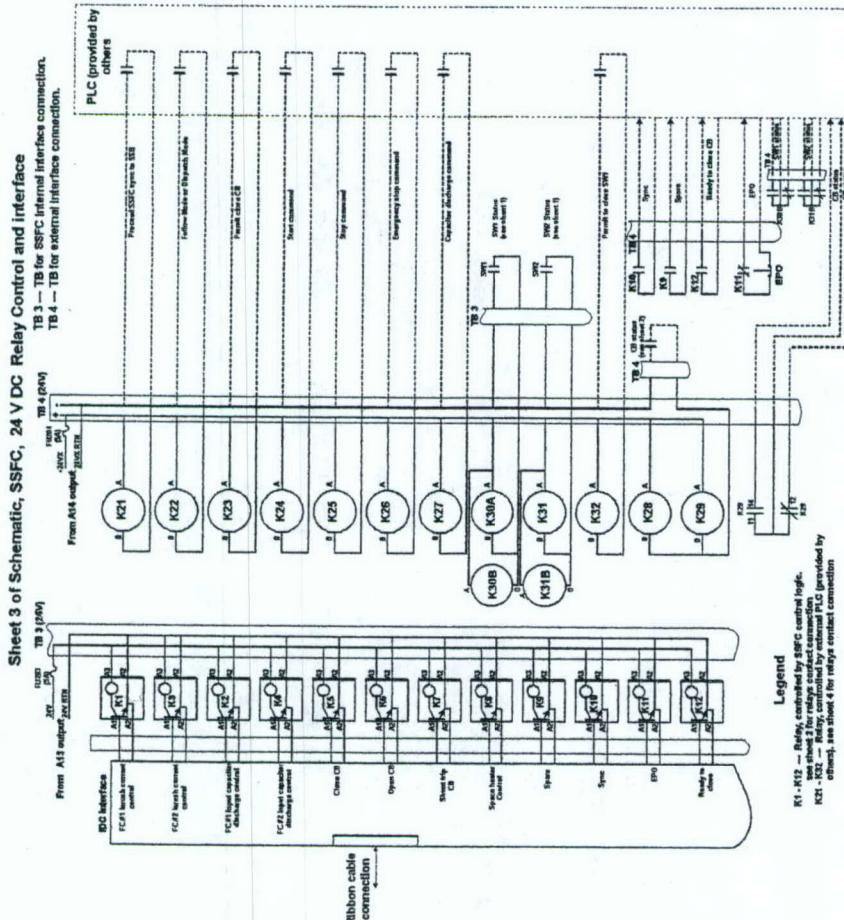
November 26, 2002



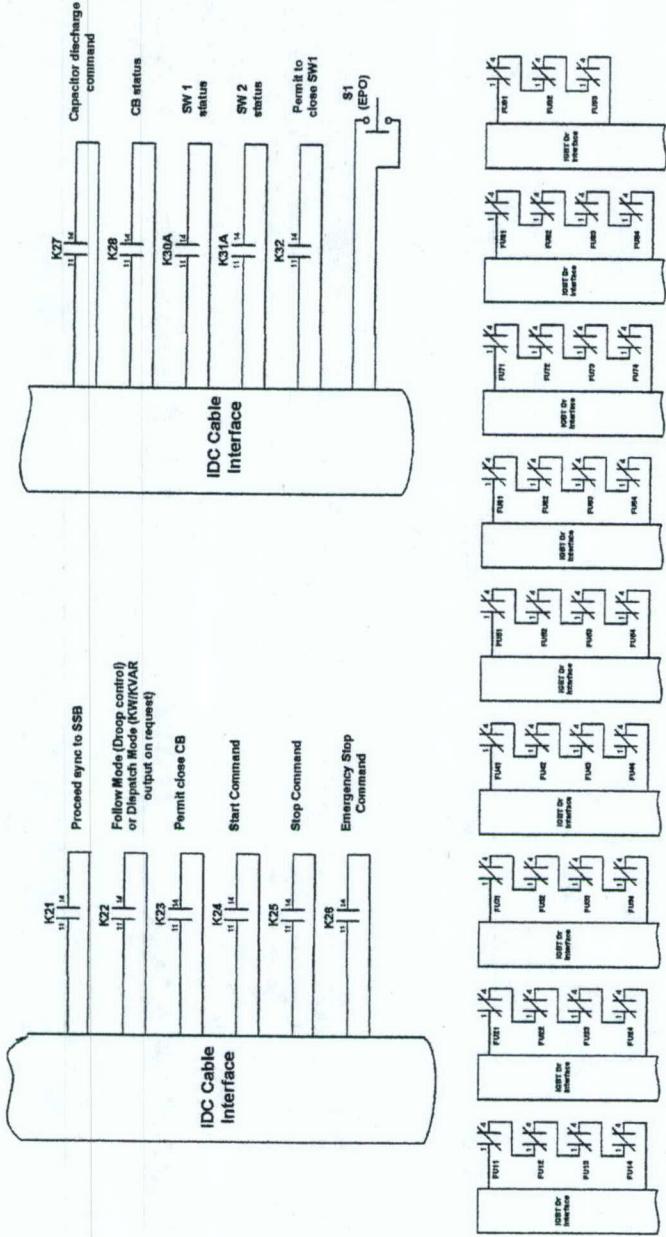
L3
communications
SPD Technologies, Inc.

Power Systems Group

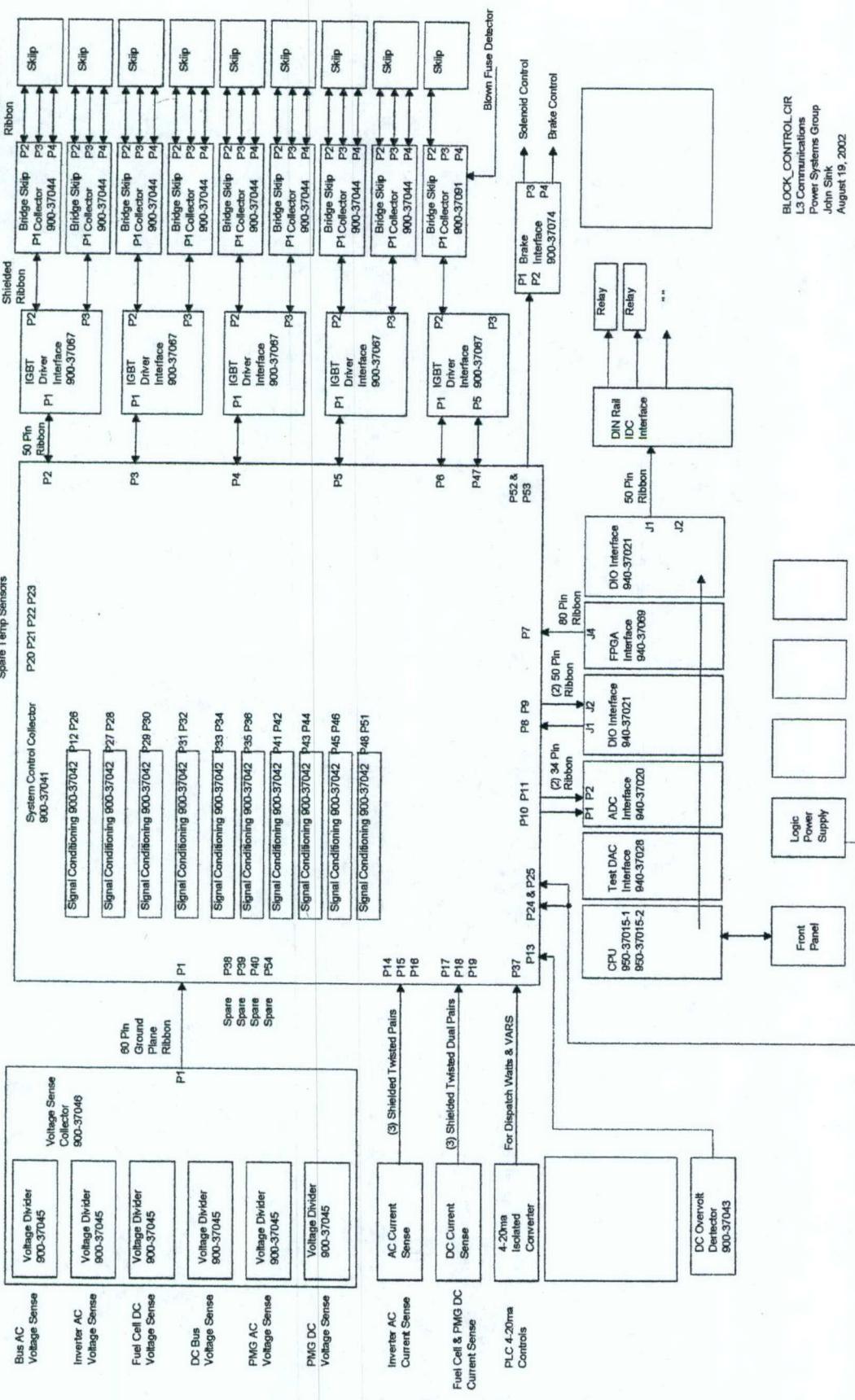




Sheet 4 of Schematic, SSFC,
24V Relay contacts connection. Relay controlled by external PLC (provided by others) See sheet 3 for Relay Coil connection
and Blown fuse micro-switch connections



Page 81 of 168
Shaded



BLOCK_CONTROL.CIR
L3 Communications
Power Systems Group
John Sink
August 19, 2002

SPD Technologies, Inc.

Power Systems Group

L3_PSG_Sample-6
12/16/2004

Appendix Number	Topic and Description	Training Module
A10	Control point and component labels	Classroom #5 Shipboard #1

The PLC Tag Names (the name that will define the I/O in the ladder logic) start with a 3letter prefix that defines the subsystem within the fuel cell plant to which their function relates. There are 16 such subsystems. They are then followed by an underscore. For the I/O which is defined on the PID drawings, the code after the underscore defines the Tag Name assigned to the I/O that is shown on the PID drawings. For the I/O that resides within the EBOP, the code after the underscore is either a defined Tag Name or is a functional description of that I/O. If the I/O is a switch and the last letter(s) end with H, HH, L, LL, or X then the last letter(s) define(s) an alarm state or the condition upon when the switch changes from one state to another. The L stands for Low, the LL stands for Low Low, the H stands for High, the HH stands for HighHigh, and the X is undefined.

See the examples below:

YYY_FFFF-SSIIQ-ZZZ

Where YYY is the subsystem, defined as follows:

AMS	-	Air Management System
ARS	-	Anode Recycle System
ECS	-	Electrical Control System
ELS	-	Electrolyzer System
FAC	-	Facility
FCM	-	Fuel Cell Module
FCS	-	Fresh Water Cooling System
FSS	-	Fire Suppression System
HDS	-	Hydro-Desulfurizer System
IAS	-	Instrument Air System
NPS	-	Nitrogen Purge System
PCS	-	Power Conditioning System
PFS	-	Processed Fuel System
WRS	-	Water Recovery System
ZRS	-	ZnO Regen System

Where FFFF is the type of I/O, defined by standard PID conventions as follows:

AA	-	Analyze Alarm
AI	-	Analyze Indicate
AIT	-	Analyze Indicate Transmit
AT	-	Analyze Transmit
B	-	Blower (this deviates from the standard PID convention)
BE	-	Burner Element
BJ	-	Burner Ignitor (this also deviates somewhat from the standard PID convention)
CT	-	Conductivity Transmit
CS	-	Conductivity Switch
DPIT	-	Differential Pressure Indicate Transmit
DPT	-	Differential Pressure Transmit
EL	-	Electrolyzer (this deviates from the standard PID convention)
ET	-	Voltage Transmit
FT	-	Flow Transmit
FV	-	Flow (Control or Modulating) Valve
HS	-	Hand (or Manual) Switch
IC	-	Current Control
IT	-	Current Transmit
LSH	-	Level Switch High
LSDL	-	Level Switch (Differential) Low
LSL	-	Level Switch Low

LT	-	Level Transmit
LV	-	Level (Control or Modulate) Valve
MC	-	Motor Control (this deviates from the standard PID convention)
P	-	Pump (this deviates from the standard PID convention)
PAC	-	PAC testing item only
PDL	-	Pressure (Differential) Switch Low
PSH	-	Pressure Switch High
PSL	-	Pressure Switch Low
PT	-	Pressure Transmit
PV	-	Pressure (Control or Modulate) Valve
SC	-	Speed Control
SV	-	Speed (Control or Modulate) Valve
TDL	-	Temperature (Differential) Switch Low
TE	-	Temperature Element (Thermocouple)
TV	-	Temperature (Control or Modulate) Valve
TW	-	Temperature Element (Thermocouple) (this deviates somewhat from the standard PID convention)
UPS	-	Uninterruptable Power Supply (this deviates from the standard PID convention)
V	-	Vibration Element (Sensor)
WT	-	Force (Vibration) Element (Sensor)
XA	-	Status Alarm
XLS	-	Limit Switch (this deviates from the standard PID convention)
XV	-	On/Off Valve
ZSC	-	Position Switch Close
ZSO	-	Position Switch Open
ZT	-	Position Transmit

The following are EBOP I/O (these do not follow PID standard conventions):

CRxx	-	Control Relay
xxDS	-	Door Switch
EFxx	-	Enclosure Fan
INxx	-	Initiate
IPDxx	-	Input Panel Device
OPDxx	-	Output Panel Device
PAAXx	-	Panel Audible Alarm
PVAXx	-	Panel Visual Alarm
TMRxx	-	Time Delay Relay
VMxx	-	Voltage Monitor

where xx usually refers to the component number or function description.

The last half of the definition, SSIIQ_ZZZ, is defined as follows:

SS refers to the PID sheet number the device is located (any number from 5 to 25). II refers to the item number that is specific to that particular sheet (any number from 01 to 60). Q refers to an alarm state or an operating condition state change (most likely L, H, or X). ZZZ refers mostly to EBOP I/O. It is used because many of the I/O is defined by functional description and not by a Tag name.

See next page for examples.

Examples:

- AMS_AT-621H

This I/O is defined as being part of the Air Management System, an Analyze Transmitter (combustible gas), is on sheet 6 of the PID drawings, has tag number 21, and has an alarm state (or functionality) of high.

- ARS_LT-1902

This I/O is defined as being part of the Anode Recycle System, a Level Transmitter, is on sheet 19 of the PID drawings, and has tag number of 02.

- PAC_PV-2502

This I/O is defined as being used only during the PAC test, is a pressure control (or modulating) valve, is on sheet 25 of the PID, and has tag number 02.

- SBS_SC-1401

This I/O is defined as being part of the Start Burner System, is a speed controller (VFD or DC motor Controller), is on sheet 14 of the PID drawings, and is item number 01.

- PFS_TE-1103-1

This I/O is defined as part of the Processed Fuel System, is a temperature element (thermocouple), is on sheet 11 of the PID drawings, and is the first part of the dual thermocouple.

- HDS_V1-10XX

This I/O is defined as part of the Hydro-Desulfurizer System, is a vibration element (sensor), is on sheet 10 of the PID drawings, and has not had a tag name assigned.

- ECS_NAVY-NIT

This I/O is defined as part of the Electrical Control System, is a fed permissive from the NAVY, and is an input permissive regarding the Nitrogen supply.

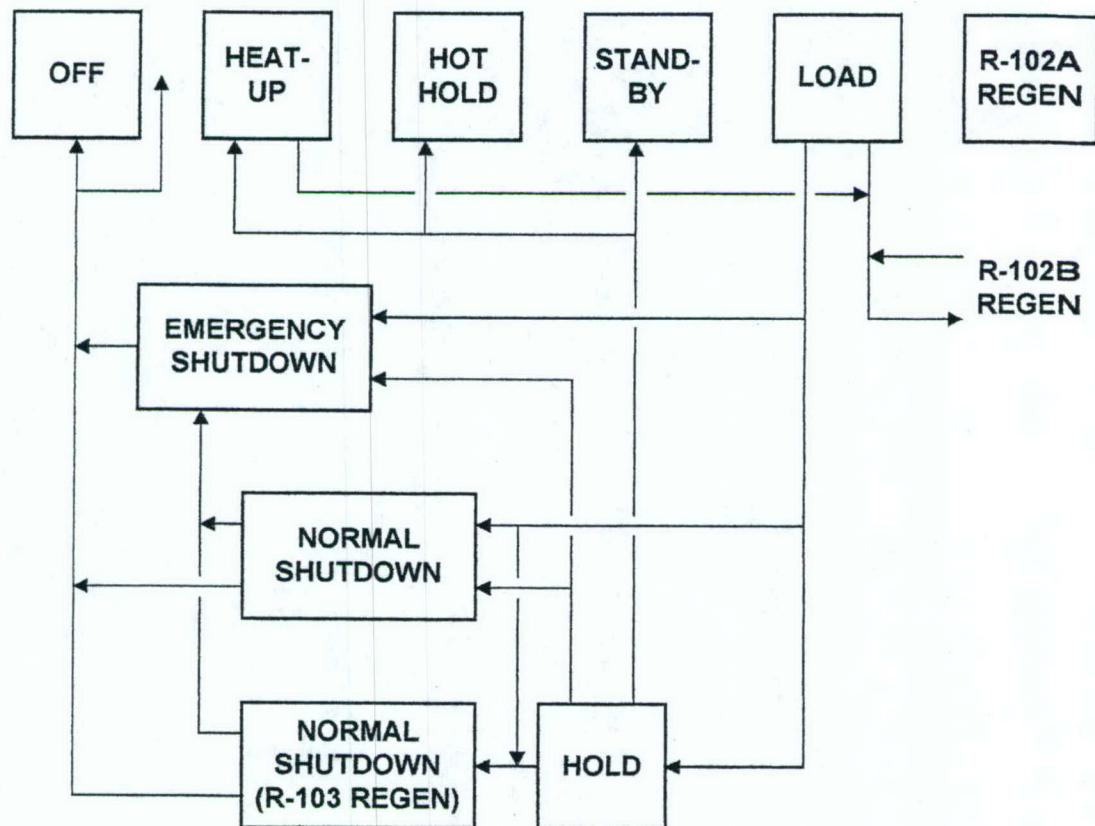
- PCS_OK-TO-CLOSE-DC-SWTCH

This I/O is defined as part of the Power Conditioning System and is a contact sending a permissive signal to the PLC stating that it is okay to close the DC circuit breaker.

- MBOP_FIRE-SUP-COOL-ENA

This I/O is defined as part of the MBOP Fire Suppression System and is an output from the PLC saying it is okay to be enabled.

Appendix Number	Topic and Description	Training Module
A11	Operating state transitions diagram	Classroom # Lab #2 Shipboard #1



State Transition Diagram for Ship Service Fuel Cell



FuelCell Energy

Appendix Number	Topic and Description	Training Module
A12	Steady State Material Balance Summary	Classroom #5 Lab #2 Shipboard #1

	100% CASE	75% CASE	50% CASE	BATTLE	ANCHOR	10% CASE	STANDBY CASE
	RATED	NORM MAX	AVERAGE	W/START BURNER	W/START BURNER	W/START BURNER	W/Start Burner High Utilization
NET POWER, % OF RATED FUEL CELL DC INPUT, KW	100.00	75.00	50.00	25.00	10.00	0.00	0.00
NUMBER OF STACKS	667.08	502.86	356.20	210.60	127.80	62.16	62.16
DC POWER PER STACK, KW	2	2	2	2	2	2	2
NUMBER OF CELLS/STACK	333.54	251.43	178.10	105.30	63.90	31.08	31.08
CELL STACK VOLTAGE	354	354	354	354	354	354	354
CELL STACK CURRENT, AMPS	264.60	284.40	300.60	314.64	324.72	330.84	330.84
PROCESS FUEL FLOW TO STACKS, LBS/HR	1267.62	899.30	593.54	340.34	200.12	93.81	93.81
TOTAL AIR FLOW TO SYSTEM, LBS/HR	231.00	163.50	107.90	60.80	33.90	16.60	16.60
CATHODE AIR FLOW, LBS/HR	9334.43	9334.43	9334.43	9334.43	9334.43	9334.43	9334.43
AIR FLOW TO MODULE INTERCOOLER, LBS/HR	6461.22	5210.03	2968.32	1362.04	1155.23	1054.94	1054.94
VENTILATOR AIR FLOW, LBS/HR	1094.67	500.00	90.00	0.00	0.00	0.00	0.00
STEAM TO ELECTROLYZER, LBS/HR	2880.31	4129.43	6369.43	7974.43	8180.43	8280.43	8280.43
MAKEUP WATER TO SYSTEM, LBS/HR	8.00	5.66	3.74	2.30	1.38	1.06	1.06
WATER TO DRAIN, LBS/HR	0.00	0.00	0.00	0.00	2.30	1.50	1.50
START BURNER FUEL FLOW, LBS/HR	26.72	8.35	2.01	2.01	0.00	0.00	0.00
START BURNER AIR FLOW, LBS/HR	0.00	0.00	0.00	0.00	365.00	200.00	13.90
BURNER QUENCH AIR, LBS/HR	0.00	0.00	0.00	0.00	0.00	193.20	215.00
TOTAL FUEL FLOW TO SYSTEM, LBS/HR	231.00	163.50	107.90	66.40	39.90	30.50	30.50
NET HEATING VALUE OF FUEL, BTU/LB	18720.00	18720.00	18720.00	18720.00	18720.00	18720.00	18720.00
NET HEATING VALUE OF FUEL, KW-HR/LB	5.49	5.49	5.49	5.49	5.49	5.49	5.49
STACK A CATHODE INLET TEMP, F	1088.23	1110.37	1158.57	1161.50	1124.48	1183.54	1183.54
STACK B CATHODE EXIT TEMP, F	1181.90	1178.14	1196.06	1151.81	1064.56	1096.65	1096.65
STACK A ANODE EXIT TEMP, F	1189.23	1164.28	1175.15	1146.62	1082.61	1129.33	1129.33
STACK B ANODE EXIT TEMP, F	1171.90	1168.14	1186.06	1141.81	1054.56	1086.65	1086.65

Appendix Number	Topic and Description	Training Module
A13	Start-up procedures	Classroom #5 Lab #5

Note: The tag numbers referenced in this document are out of date as of the time of this report, with final tag numbers yet to be determined.



START-UP PROCEDURE

This procedure describes the transitions from OFF through HEAT-UP to HOT HOLD to STANDBY, and then to LOAD.

OFF-MODE

In the OFF mode an inert nitrogen blanket is maintained on the prereformer and cell anodes. Unit nitrogen manual block valve V-501 is open.

The PLC and HMI are active.

Instrument air manual shutoff valve V-2101 is open.

All block valves are in their unpowered fail positions except: NPS-XV-1007, NPS-XV-1310, ARS-XV-1505, PFS-XV-1303, HDS-XV-1016, PFS-XV-1225, WRS-XV-1106, ARS-XV-1808, HDS-XV-701, HDS-XV-713, and HDS-XV-813. The latter three block valve positions prevent salt air from entering the ZnO and HDS reactors. The other block valve positions support a nitrogen blanket on the prereformer and cell anodes.

Control valve NPS-PV-1520 is active and maintains a nitrogen pressure of 5 iwg at the anode exhaust.

Overpressure control is active: FCM-DPI-1515 opens ARS-XV-1505 on anode overpressure.

All other control valves are in their unpowered fail positions except WRS-PV-1901, which is held closed.

Condensate Tank S-101 is filled with water to prevent nitrogen leakage.

HEAT-UP

From the OFF state there are 6 stages in the HEAT-UP transition to HOT HOLD as follows:

STAGE 1 - PREPARE FOR START HEATING

During this stage Auxiliary Systems are prepared for Start Heating

Confirm PLC and communications ready to start.

Confirm Burner Management System BMS ready to start.

Confirm Electrolyzer controller and communications ready to start.

Confirm PCS controller and communications ready to start.

Verify Navy-side permissives to resume start sequence.

Verify 2 psig potable water line pressure.

Verify instrument air pressure.

Verify nitrogen interface pressure and nitrogen cylinder pressure.

Switch auxiliary power to external supply with transfer switch and confirm position.

Close the dc no-load disconnect switches between the stacks and PCS and confirm.

- Open manual valves on burner fuel and gas trains and open manual valve on atomizing air line.
- Fill and activate the condensate system, P-102, and P-105.



Open V-1805 (potable water manual block valve).

Activate S-101 level control ARS-LY-1812: ARS-XV-1808 opens on low level and closes on high level. Level control ARS-LY-1812 is always active, except in the OFF mode.

Start P-102 to fill Condensate System and confirm P-102 activation.

Activate WRS-PV-1815 to maintain P-102 discharge pressure.

Confirm P-102 discharge pressure.

Start P-105, confirm activation, and activate flow control WRS-FV-1910 when WRS-FE-1914 registers flow.

Circulate flow through Demineralizer System WT-102 and back to E-115.

Proceed to the next step when WRS-AE-1A (if bed set A is online) or WRS-AE-1B (if bed set B is online) shows 1 megohm water quality or better.

- Fill and activate the freshwater cooling system

Pressurize V-102 to 28 psig with compressed air or nitrogen

V-1805 (potable water manual block valve) is still open from previous step.

Open potable water block valve FWC-XV-2004.

Open and monitor all manual high point vent valves to insure that air is removed. Close high point vent valves when water overflows out the vent(s).

Close XV-2004.

Activate FWC water make-up control FWC-HS-2004: FWC-XV-2004 opens when FWC-PT-2003 pressure falls below a design minimum. FWC-HS-2004 remains active throughout the remaining steps.

Start P-104 and confirm.

Activate Coolant System Treatment Unit WT-103 and confirm.

- Activate the nitrogen valve purges

Unit nitrogen manual valve V-501 is open from previous step.

Open V-701, adjust purge flow with V-702 for L. P. Header Valve Purge

Open V-801, adjust purge flow with V-802 for H. P. Header Valve Purge

- Confirm water fogging system ready.
- Confirm that HDS-XV-516, HDS-XV-524, and ZRS-XV-1111 are all still closed.
- Open manual valve V-503 and confirm fuel to the power plant interface. Confirm a minimum pressure of 70 psig via HDS-PI-513 (P-101 suction pressure).
- Activate B-104 on start setting to vent the enclosure and confirm.
- Confirm position of all valves for Stage 1.

**STAGE 2 – INITIAL CELL STACK WARMING**

During this stage the temperature of the cell stacks is raised sufficiently above ambient temperature to avoid moisture absorption from the air during the later warming stage.

During this stage N₂ is circulated through the cell stack anodes by B-102. The nitrogen is heated in R-103 by the vessel heaters H-108A and H-108B.

NPS-PV-1520 continues to maintain 5" iwg pressure on the anode exhaust.

Confirm the closure of valves: WRS-XV-1105, WRS-XV-1106, ELS-XV-2203, HDS-XV-1016, HDS-XV-1021, ARS-XV-1803, PFS-XV-1306, ARS-XV-1505, PFS-XV-1303, PFS-XV-1307, ARS-XV-1405, and WRS-PV-1901. These valves have been previously closed.

Flow recycle around B-102 is set with ARS-FV-1809 on STAGE 2 position setting.

Open valve ARS-XV-1805 to allow B-102 to flow directly to E-102.

Open valve PFS-XV-1225 to circulate N₂ from R-103 to the exit of E-101, bypassing E-101 and PFS-TV-1601.

Close valve PFS-XV-1519 shutting the bypass around the cell stacks and directing the exit of E-101 to E-108. All the N₂ from R-103 through PFS-XV-1225 flows through the cell stack RUs and anodes.

Valve ARS-XV-1806 is left open and NPS-PV-1520 remains active.

Start B-102 (Ramp up speed to final STAGE 2 speed setting to limit stack seal pressure differentials). Maximum pressure across the anode/hot box air seals is limited to 15 iwg using FCM-DPI-1515.

Activate H-108A/B on the R-103 vessel to its warming control schedule. The H-108A/B power is controlled to maintain nitrogen inlet temperature to the cell stacks at 90 °F (TBD) above the anode exit temperature from the cell stacks.

When the cell stacks have been warmed 20-40 °F TBD above the ambient air temperature proceed to Stage 3.

**STAGE 3 – PREPARE FOR FUEL PROCESSING SYSTEM HEATING****STAGE 3A**

- **Prepare for HDS heating**

Close valves isolating the HDS from the fuel supply, electrolyzer, and prereformer. Switch valves for flow from H-103 to R-101, R-102B and back to E-118 in series through 2" pipes. Confirm the closure of valves HDS-XV-802, HDS-XV-811, HDS-XV-831, HDS-XV-832, HDS-XV-812, HDS-XV-815, HDS-XV-816, HDS-XV-817. These valves have been previously closed.

Confirm that the following, corresponding bleed valves are open: HDS-XV-810, HDS-XV-833, HDS-XV-820, HDS-XV-818. These valves have been previously open.

Open valves ZRS-XV-612, ZRS-XV-614, HDS-XV-819, HDS-XV-821, HDS-XV-809, HDS-XV-813, ZRS-XV-908, ZRS-XV-909, and ZRS-XV-903.

Close corresponding bleed valves ZRS-XV-615, HDS-XV-822, and HDS-XV-814 and ZRS-XV-916.

Position ZRS-FV-914 to full closed.

Confirm that ZRS-PV-915 is full open. This valve was previously open.

- Isolate R-102A

Confirm the closure of valves HDS-XV-701, HDS-XV-711, HDS-XV-718, HDS-XV-716, HDS-XV-713, HDS-XV-709, HDS-XV-722, HDS-XV-724, HDS-XV-726, HDS-XV-727, HDS-XV-715, HDS-XV-720, ZRS-XV-918, and ZRS-XV-913.

Confirm that the following bleed valves are open: HDS-XV-710, HDS-XV-728, HDS-XV-723, HDS-XV-714, HDS-XV-717, and HDS-XV-712.

Open NPS-XV-912 (40 psig nitrogen supply) and confirm.

Purge with nitrogen through ZRS-XV-903 and ZRS-PV-915 to Exhaust Header for TBD minutes.

STAGE 3B

- **Pressurize the ZnO regeneration loop and HDS Recycle loop with N₂ to 40 psig.**

After purge is complete.

Valve NPS-XV-912 (40 psig nitrogen supply) remains open.

Close ZRS-XV-903 and close ZRS-PV-915.

Position ZRS-FV-914 to full open and confirm.

Open valve HDS-XV-1008 (B-105 suction) and confirm.

Confirm the closure of valves: ELS-XV-1011, HDS-XV-1015, HDS-XV-1022, and HDS-XV-1023.

The system pressurizes to 40 psig.

STAGE 3C

- **Circulate nitrogen through the ZnO regeneration loop and HDS Recycle loop.**



Close NPS-XV-912 (40 psig nitrogen supply) and confirm.

Start B-105 (and confirm) circulating N₂ through E-111, to E-105, R-101, R-102B, back through E-111, to E-110, S-102 and back to B-105.

Start B-103 (and confirm) circulating N₂ through E-118, to H-103, R-101, R-102B and back through E-118 to E-114 and back to B-103.

STAGE 3D

- Prepare for Prereformer heating

Open PFS-XV-1306 and confirm.

Close PFS-XV-1225 and confirm.

Confirm that PFS-SV-1305 is positioned to bypass. This was previously positioned to bypass.

Open valve PFS-XV-1519 (and confirm), bypassing N₂ around the cell stacks. Only a very small amount of N₂ flows through the cell stack RU's and anodes.

Kick back valve ARS-FV-1809 is positioned to its STAGE 3D position setting. ARS-FV-1809 stays open to provide flow through B-102 and avoid surging B-102 while flowing N₂ through the prereformer loop.

Confirm that PFS-TV-1601 remains in its fail-safe through position, allowing cold-side flow through E-101.

Position PFS-TV-1602 to its through position, allowing cold-side flow through E-102.

STAGE 3E

- Prepare for Boiler heating

Switch valves directing water from E-106 to E-107, through the boiler startup line, and to the hot side inlet of E-108.

Open valve WRS-XV-1106 and confirm.

Confirm that WRS-PV-1104 is open. This valve was previously open.

Activate P-103 on its start setting (TBD water flow to E-107 and E-106) and confirm.

Activate the boiler pressure control WRS-PV-1104 to start pressure (TBD).

Water vents through WRS-PV-1104 to E-108.

**STAGE 4 - HEAT HDS & PREREFORMER, AND WARM CELL STACKS FURTHER**

During this stage the HDS and Prereformer systems are heated by the start burner on raw fuel and by electric heaters on the reactor vessels. During this stage the cell stacks are warmed to about 300°F by preheated air from E-104 flowing through the cell stack cathodes and hot box. This flow also prevents back flow of sulfur bearing exhaust from H-102 into the cell stacks.

- **Start H-102 on raw fuel**

Confirm that HDS-TV-1605 remains in its fail-safe through position, allowing cold-side flow through E-105.

Confirm that WRS-TV-1606 remains in its fail-safe through position, allowing cold-side flow through E-116.

Position ARS-TV-1604 to its through position (and confirm), allowing cold-side flow through E-104 and air preheat. Previously this valve was in its fail-safe bypass position.

Open the raw fuel shutoff valve HDS-XV-516 and confirm.

Confirm proper raw diesel pressure range with HDS-PT-513. This is also alarmed in the PLC with HDS-PI-513.

Confirm low temperature with SBS-TE-1402. Low temperature interlock will also be proven by the BMS with temperature switch SBS-TSH-1403 via SBS-TE-1403. The switch status is also monitored by the PLC.

Confirm that SBS-TV-1406 is at full bypass position. Previously this valve was in its full bypass position. This directs H-102 exhaust to E-101 with no exhaust flow to H-101.

Set ARS-FV-1413 to its start position (and confirm, if hydraulic valve). This start position corresponds to flowing a (TBD) fraction of preheated process air to H-101, and on to the cell stack #1 cathode.

Start B-101 to its STAGE 4 start setting and confirm.

At this point there is cold-side flow through E-101, E-102, E-105, E-106, E-107, E-116 and E-104.

For the rest of the start procedure, ensure that flow through ARS-FE-1413 is always positive.

Slowly ramp up SBS-FV-1407 flow to its start setting (608 SCFM) to quench the burner

primary flow to 1200 °F while delivering 1×10^6 Btu/hr. Confirm the ramp following with SBS-FE-1407.

Open B-106 inlet air valve SBS-XV-1404 and confirm.

Start B-106, confirmed with SBS-XV-1401, to maximum setting (60 Hz), and confirm frequency.

Air flow will make pressure switch SBS-PS-1427, which will be proven by the BMS.

The BMS will prove interlocks: combustion fan air pressure SBS-PS-1427, low gas pressure SBS-PSL-1422, high gas pressure SBS-PSH-1423, and high temperature limit SBS-TE-1403.

After interlocks are satisfied, start purging cycle:

BMS notifies PLC to drive diesel firing rate motor SBS-TV-1402A to HIGH FIRE position. HIGH FIRE is proven and BMS starts pre-determined count.



BMS notifies PLC after 2.5 minutes to drive the firing rate motor to return to LOW FIRE position.

BMS signals that the burner can be started with from the PLC.

Return B-106 to its minimum ignition speed (12 Hz TBD) for ignition of the burner at 2.0 gal/hr.

Set SBS-TV-1402A to ignition setting, corresponding to ignition at 2.0 gal/hr.

Oil shutoff valves SBS-XV-1417A and SBS-XV-1417B (both confirmed with SBS-XV-1410) and oil shutoff valve SBS-XV-1420 are all opened.

Atomizing air valve SBS-XV-1410 is opened.

Start ignition.

Confirm diesel fuel ignition with SBS-BE-1408A.

Activate combustion air control SBS-SC-1401 to provide excess air corresponding to raw diesel.

Activate the temperature control SBS-TV-1402A to slowly ramp (rate TBD) up the fuel flow to H-102. The TBD ramp rate slowly raises the temperatures in the TMS heat exchangers. The end condition is an exit mix temperature of 1200 °F from H-102 to E-101.

- **Warm the Cell stacks and Hot Box**

Preheated air from E-104 warms H-101, the hot box and cell stacks as it flows through the cell stack cathodes and out the through the TMS.

Ramp up AMS-TV-1501 to its start setting (TBD), while ensuring positive flow through ARS-FE-1413. This brings preheated air from E-104 into the hot box. Cell stack #2 is warmed after stack#1 and the hot box by the combined flow leaving Stack #1 and air from TV-1501.

- **Heat HDS with Nitrogen**

Open ZRS-XV-903 to allow pressure relief through PV-915. This valve was previously closed.

Activate pressure relief control ZRS-PV-915 to relieve pressure at 40 psig.

Activate the H-103 power control to the start ramp so that the nitrogen exit temperature is about 100 °F TBD above the exit temperature from R-101 and heats the bed at about 100 °F /hr.

Activate vessel heaters H-105 on R-101 and H-107 on R-102B to start (2kW TBD) settings.

Control vessel electric heater's power so that R-101, and R-102B are heated at a rate no greater than 100 °F/hr to 720 °F.

Set HDS-TV-1605 to 10% minimum (TBD) flow through E-105 to control the temperature ramp-up rate in R-101 during start heatup.

E-105 is heated by the start burner exhaust.

E-111 and piping are heated by nitrogen circulated by B-105.

- **Heat prereformer loop**

Activate the E-102 temperature control to limit temperature out of E-102 to ramp R-103 at 100 °F/hr (max) to 900 °F and maintain 10% (TBD) minimum flow through E-102 during start heatup

Continue power to vessel heater H-108A/B on R-103 at start 10 kW (TBD) setting.

R-103 is heated by the vessel heater and nitrogen circulated by B-102 to 900 °F



STAGE 5 -OPERATE THE HDS & PRESSURIZE THE PREREFORMER, AND HEAT R-102B

STAGE 5A

When the HDS loop has been heated to 700°F, and the Prereformer loop heated to 900 °F.

- **Isolate R-101 and R-102B from the Zinc Oxide Regeneration System (ZRS)**

Deactivate the ZnO Regen Heater H-103.

Deactivate the ZnO Regen Boost Blower B-103.

Switch valves to isolate R-101 and R-102B from the heating loop.

Close valves ZRS-XV-612, ZRS-XV-614, ZRS-XV-908, and ZRS-XV-909.

Open corresponding bleed valves ZRS-XV-615 and ZRS-XV-916.

Close valve ZRS-XV-903.

- **Activate EL-101**

Start B-107 (EL-101 cabinet vent fan).

Confirm P-105 is still running from Stage 1 (water supply to EL-101).

Confirm P-104 is still running from Stage 1 (coolant supply to EL-101).

Confirm 40 psig nitrogen is still active from Stage 1.

Confirm remaining PLC interlocks before initiating EL-101 start sequence.

Initiate EL-101 startup sequence.

Heat is maintained in the HDS by H-105, H-107, and E-105 while EL-101 cycles through its startup sequence.

B-105 continues to circulate.

- **Pressurize the HDS with Hydrogen**

When EL-101 startup conditions are verified.

Open ELS-XV-1011.

Pressurize the system to 900 psig with hydrogen from EL-101.

B-105 continues to circulate gas as the system is pressurized.

Vessel heaters on R-101 (H-105) and R-102B (H-107) remain active at operating power set points to help maintain heat in HDS reactors.

STAGE 5B

- **Operate the HDS and fill S-102**

When the HDS loop is at operating pressure and temperature.

Open HDS-XV-524 and confirm.

Hydrogen continues to flow to the HDS to maintain the pressure in R-101 from HDS-PT-602.

Start P-101 and confirm.

Activate the S-102 level control and the fuel control at start setting. Raw fuel flows to the HDS.

Confirm that HDS-XV-1016 is closed. This valve was previous in its closed position.

Open HDS-XV-1015 to vent light hydrocarbons to the H-102 burner.



Activate HDS-FV-1005 on STAGE 5B pressure control to reduce hydrogen pressure to 2 psig requirement to start burner.

Confirm PLC interlocks for dual operation on diesel fuel and gas.

Activate split-range burner control.

After BMS interlocks are satisfied.

SBS-TV-1402B control is activated.

Light hydrocarbons and hydrogen are vented to the H-102 burner through HDS-XV-1015. (The 2% vent rate is well below the limit of 15 lbs/hr, which H-102 can accommodate.)

S-102 is filled with desulfurized fuel.

STAGE 5C

- **Pressurize the Prereformer loop.**

When R-103 is at 900 °F and S-102 is filled and confirmed.

Anode recycle blower B-102 remains operational in flow recycle mode. ARS-FV-1809 is positioned to STAGE 5C setting. B-102 speed is set to STAGE 5C setting.

NPS-PV-1520 continues to maintain 5 iwg pressure on the anode exhaust.

Isolate the prereformer loop from B-102.

Close bypass valves ARS-XV-1805, ARS-XV-1806 and PFS-XV-1519.

Close valve PFS-XV-1225 directing prereformer flow to PFS-FV-1301.

PFS-XV-1306 is closed.

Close WRS-XV-1106.

Deactivate boiler start pressure control WRS-PV-1104 and move WRS-PV-1104 to its fail-safe open position.

The boiler pressure will increase.

When the boiler pressure reaches its design pressure.

Open WRS-XV-1105.

Activate the boiler pressure control (PFS-PT-1101 sends a signal to WRS-FIC-1905 to maintain pressure) to normal 964 psig by varying P-103 stroke.

Activate the prereformer loop pressure control (NPS-PT-1223 sends a signal to PFS-FIC-1109 to control prereformer exhaust pressure to 360 psig).

Steam to the eductor is initiated, drawing prereformer exhaust to the eductor suction.

After 5 min TBD fuel flow from the fuel control valve follows steam flow according to a steam to fuel mass ratio of 3.2 to 1.

Open HDS-XV-1021.

Flow control HDS-FV-1004 is initiated (fuel mass flow setpoint follows measured steam flow WRS-FE-1109).

Switch HDS vent gas to prereformer loop.

Open HDS-XV-1016, and close HDS-XV-1015.

HDS-FV-1005 remains active, as in STAGE 5B, to reduce hydrogen pressure to 2 psig requirement to start burner.



Burner operation remains on split-range control, as in STAGE 5B.

Pressurize the prereformer loop to 360 psig with steam through EJ-101 and fuel from S-102 proportional to steam flow.

Maintain temperature with vessel heater H-108A/B (on STAGE 5C setting) and heat from E-102.

STAGE 5D

- **Heat R-102A**

After R-102B is heated with R-101 and the loop has been isolated from the regeneration loop, R-102A reactor is joined to the regeneration loop for heat-up as follows:

Open block valves HDS-XV-722, HDS-XV-724, HDS-XV-716, HDS-XV-718, joining R-102A to the regeneration loop.

Close corresponding bleed valves HDS-XV-723 and HDS-XV-717.

ZRS-XV-913 still remains closed (confirm), isolating the regen loop from the cathode exhaust stream.

Open valve ZRS-XV-903 and confirm.

Activate ZRS-PV-915 overpressure control to 40 psig.

Activate B-103 on STAGE 5D setting.

B-103 flows nitrogen through E-118, H-103, R-102A and E-114.

Activate the H-103 heater control to limit nitrogen to the R-102A bed for a maximum bed heating rate of 100 °F/hr.

Continue heating until R-102A exit is at 720 °F.

When R-102A exit temperature is 720 °F.

Depressurize the ZnO Regen loop by opening ZRS-PV-915 until pressure is 0 psig.

Maintain at 720 °F using H-106, H-103 as required and B-103 circulation until R-102A transition is scheduled.



STAGE 6 OPERATE THE PREREFORMER AND HEAT THE CELL STACKS

- **Transition the start Burner to Desulfurized fuel**

Open desulfurized fuel valve HDS-XV-1022.

Close raw fuel valve HDS-XV-516.

- **Flow processed fuel to Start Burner**

When the prereformer loop is at pressure and temperature, and the cell stacks are at about 300 °F from STAGE 4.

Fully bypass TG-101 with PFS-SV-1305 and confirm position.

Open PFS-XV-1306 (and confirm), allowing anode exhaust to flow to the cell stacks.

Anode exhaust is still isolated from H-101 by ARS-XV-1405 (verify still closed).

B-102 is still in flow recycle mode (ARS-FV-1809 placed in STAGE 6 position).

Connect Anode exhaust to H-102 from the exit of B-102.

Open ARS-XV-1803 and confirm.

Turn down the liquid fuel with SBS-TV-1402A to a low (TBD) setting.

Split-range burner control is still active.

Open PFS-FV-1301 to start (TBD) setting.

Processed fuel flows through the cell stacks to E-108 to H-102.

The anode flow control setting provides processed fuel to H-102 at a

from oxidation related to air on the cathodes as the cell stack is heated.

The liquid fuel to H-102 is supplemented by the processed fuel from the anodes providing sufficient fuel to heat the cell stacks and

Keep the HDS and prereformer loops at required process conditions.

At this point there is processed air flowing through the cathodes and processed fuel flow through the anodes with the cell stacks and hot box at 300 °F.

- **Heat cell stacks with H-102 exhaust in cathodes**

Set SBS-TV-1406, splitting H-102 exhaust between H-101 and E-101.

The SBS-TV-1406 split ensures heat to the prereformer and HDS while the stacks are heating.

A portion of H-102 exhaust mixes with process air and flows through H-101 and then to the cell stack cathodes.

Temperature control on H-101 exit to the cell stacks is set to a cell stack 40 °F/hr (TBD) heating rate. This is accomplished by controlling the B-101 flow and flow setting with ARS-FV-1413.

As the cell stacks are heated and open circuit voltage develops the DC input



capacitors to the PCS are charged.

When the cell stacks are at hot-hold temperature (TBD) then proceed to the next step.

TRANSITION TO HOT HOLD

- **Switch anode exhaust flow to H-101**

Open ARS-XV-1405 (and confirm) to H-101.

Close ARS-XV-1803 (and confirm) to start burner.

- **Continue running start burner**

The start burner remains operational to maintain the cells and hot box at hot-hold temperature.

TRANSITION TO HOT STANDBY

- **Ramp up temperature from hot-hold temperature to standby temperature**

If the burner is not required to maintain operational temperature, then,

Close SBS-TV-1402A.

Close SBS-FV-1407.

Close SBS-XV-1404 (and confirm).

Position SBS-FV-1406 for full flow to H-101.

If the burner is required (established by testing) then continue burner operation.

The cell stacks and hot box are ramped up to 1150 °F.

When the cell stacks are at 1150 °F, process conditions in the prereformer and HDS are at acceptable levels, the cell stacks are at open circuit voltage and dc capacitors are charged, the power plant is in HOT HOLD mode. When process conditions are fully stabilized the power plant can be transitioned to hot standby as follows.

- **Transition the turbo expander from stall to rated speed**

Activate speed control PFS-SV-1305 to slowly increase speed on unloaded expander and then hold at 70% rated speed.

Activate intercept valve PFS-XV-1319.

- **Activate the PCS to synchronize output with the load bus**

- **Convert all control loop logic from “start” mode to “Load” mode**

- **Confirm PCS output characteristics, 450VAC and 60Hz**

- **Transfer Auxiliary power from external supply to internal**

- Signal Transfer switch position to internal supply (and confirm).



- Auxiliary power loads the fuel cell stacks to standby parasitic power.
- **Transfer expander speed control from PLC to PCS**
 - PCS controller electrically loads the expander to control speed.
 - Intercept valve remains active.
 - Electronic brake is activated.

The AC output breaker is open.

The HDS system maintains the desulfurized fuel level in S-102.

The electrolyzer EL-101 responds to hydrogen flow demand to maintain HDS loop pressure.

The Prereformer processes a low flow of fuel to support the (TBD) DC current demand.

Pressure in the prereformer loop is maintained by the bias input on the ejector steam flow control.

The processed fuel flow is biased to maintain thermal conditions by sensing exhaust temperature.

The cell stacks have a fuel utilization less than 75% (TBD) and water makeup maintains level in S-101.

Electric heaters on the prereformer and HDS vessels are active to maintain process temperatures.

When the system process conditions have stabilized at the stand-by conditions the PCS can be switched to a load following mode or dispatched power mode.

In dispatched mode a signal from the HMI user interface activates the power plant to ramp up the output at a normal 1 %/min (TBD) rate or rapid 1 %/sec (TBD) rate.

In load following mode the PCS maintains output bus voltage by adding AC current to the load bus to meet demand. When other power plants are also supplying current to the load bus the PCS uses voltage droop control to share load with the other power plants.

Appendix Number	Topic and Description	Training Module
A14	Analysis of ZnO Regeneration Sequence	Lab #5

Note 1: References in this document call out tables of information no longer current and therefore not provided in this report.

Note 2: The tag numbers referenced in this document are out of date as of the time of this report, with final tag numbers yet to be determined.

**ANALYSIS OF ZNO REGENERATION SEQUENCE**

Prepared by R.A.Sanderson 8/7/02

The ZnO regeneration sequence includes 9 steps as follows

1. Bring alternate bed R-102A (R-102B) on line; isolate the ZnO reactor R-102B (R-102A).
2. Depressurize the R-102B (R-102A) from 920 psig to atmospheric pressure, venting through E-120 collecting F-76 in S-104 and venting above 350 psi to the R-103 loop and venting below 350 psig to the vent header.
3. Purge the hydrogen and F-76 from the R-102B (R-102A) with nitrogen
4. Heat the R-102B (R-102A) from 700 °F to 1000°F with nitrogen which is heated by H-103
5. Regenerate the R-102B (R-102A) with oxygen provided by recirculating system exhaust
6. Purge the R-102B (R-102A) with nitrogen to remove any trace of oxygen
7. Cool the R-102B (R-102A) from 1000 F to 700 °F and hold at 700 °F
8. Pressurize R-102B (R-102A) with hydrogen from the electrolyzer EL-101 to 920 psig
9. Reconnect the R-102B (R-102A) into the HDS system in parallel with R-102A(R-102B)

The time for a complete ZnO bed regeneration cycle is shown in Table 1.

STEP	PROCESS	TIME, HOURS
1	ISOLATE	0.02
2	DEPRESSURIZE	0.38
3	PURGE HYDROGEN	0.166
4	HEAT	5
5	REGENERATE	8
6	PURGE OXYGEN	0.166
7	COOL	4.5
8	PRESSURIZE WITH H ₂	1.04
9	ACTIVATE	0.02
TOTAL		19.3

The following describes each step and the basis for the time required for each of the steps.

Step 1 In this step the ZnO vessel R-102B (R-102A) is isolated from the HDS system by closing the double block Valves XV-819, XV-821, XV-809, XV-813 (XV-701, XV-711, XV-709, XV-713) and opening the bleed valves XV-822, XV-814 (XV-710, XV-714). ZnO vessel R-102A (R-102B) is switched into service by opening the double block valves XV-701, XV-711, XV-709, XV-713 (XV-819, XV-821, XV-809, XV-813) and closing the bleed valves XV-710, XV-714 (XV-822, XV-814). Estimated time is <1 minute to close various isolation valves and confirm the interlocks.

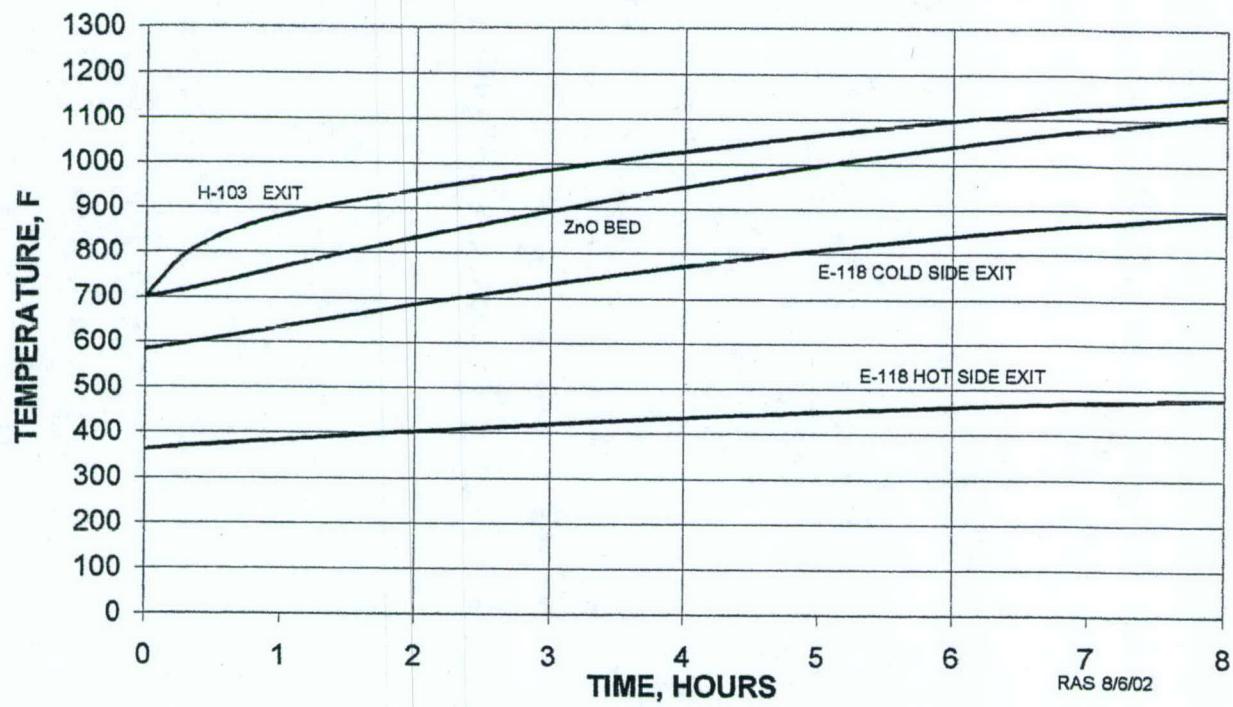
Step 2 In this step the ZnO vessel R-102B (R-102A) is connected to fuel condenser E-120 by opening double block valves XV-831, XV-832 (XV-726, XV-727) and closing bleed valve XV-811 (XV-724). The fuel condenser exhausts to the ZnO depressurization separator S-104, which exhausts to the prereformer through block valve XV-1112, automatically opened when pressure exceeds 350 psig. This represents the first stage of



depressurization. The flow rate of hydrogen and diesel fuel is controlled by FV-1107. Depressurizing to near atmospheric pressure is estimated to require 0.38 hours based on 10 lb of gas in R-102, the gas filters and the piping up to the block valves. It is also based on a controlled depressurizing flow of 26 lb/hr which is the basis for sizing the depressurizing fuel condenser E-120. In the second stage of depressurization (350 psig to 70 psig), hydrogen now vents from S-104 to the vent header by automatic closing of block valve XV-1112 and automatic opening of block valve XV-1108 (both, when pressure drops below 350 psig). Pressure control valve PV-1110 is active during this stage and maintains pressure to be at least 70 psig. In the third stage of depressurization, the liquid fuel collected in S-104 (contains liquid fuel and hydrogen at 70 psig) is removed and sent to the fuel pump suction by opening block valve XV-1111 and re-closing block valve XV-1108. Block valve XV-1111, under control by LI-1115 during this stage, is re-closed once the level in S-104 has reached its lower limit.

Step 3 In this step the ZnO vessel R-102B (R-102A) is connected to the regen loop by opening block valves XV-816, XV-834, XV-802, XV-811 (XV-716, XV-718, XV-722, XV-724) and closing bleed valves XV-818, XV-810 (XV-717, XV-723). The 40 psig nitrogen source is connected into the system by opening block valve XV-912. Block valve XV-918 is opened, purging gases to the vent header. Regen flow control valve FV-914 is closed during this step and pressure control valve PV-915 is set to open position. After the purge, the 40 psig nitrogen source is disconnected by closing block valve XV-912. Block valve XV-918 is left open until the loop pressure reduces to 2 psig. Afterwards, block valve XV-918 is closed. Purging the hydrogen and desulfurized F-76 from the reactor including the regeneration loop system with nitrogen is expected to require 10 minutes based on total volume of gas of 7 Ft³, a three volume purge and a nitrogen purge flow of 2.1 cfm.

Step 4 In this step the ZnO bed R-102B (R-102A) is heated from 700 °F to 1000°F. Block valve XV-903 is opened, connecting the loop exhaust to the exhaust header. Pressure control valve PV-915 is active during this step and relieves to the exhaust header to maintain pressure at 2 psig. Nitrogen, circulated by B-103 at 373 lb/hr and near atmospheric pressure, transfers heat from the 8 kW heater H-103 to the ZnO vessel. Heat is also provided by the 2 kW heater on the vessel wall. The time for heating is estimated at 5 hours as shown in Figure 1. Temperatures at the exit of the blower B-103, the E-118 cold side exit, the H-103 exit and the ZnO vessel exit are shown versus time. Assumptions and details of the analysis are presented in Table 1

**ZnO BED HEAT UP BEFORE REGENERATION**



Step 5 In this step the ZnO bed R-102B (R-102A) is regenerated by recirculating depleted plant exhaust. The ZnS in the bed is regenerated to ZnO with oxygen in the recirculated regen stream in the following reaction.



Cathode exhaust supply is connected into the loop by opening block valve XV-913. Pressure valve PV-915 is still active during this step and relieves through block valve XV-903, which is still open. Flow control valve FV-914 is activated and changes the recycle flow rate to control the peak exotherm temperatures during oxidation of ZnS. The recycle flow rate affects the oxygen content into the reactor; a higher recycle rate lowers the oxygen content while a lower recycle rate increases the oxygen content. The oxygen transmitter AT-905, located at B-103 discharge, is used to bias the recycle flow rate to account for varying oxygen content in the cathode exhaust stream.

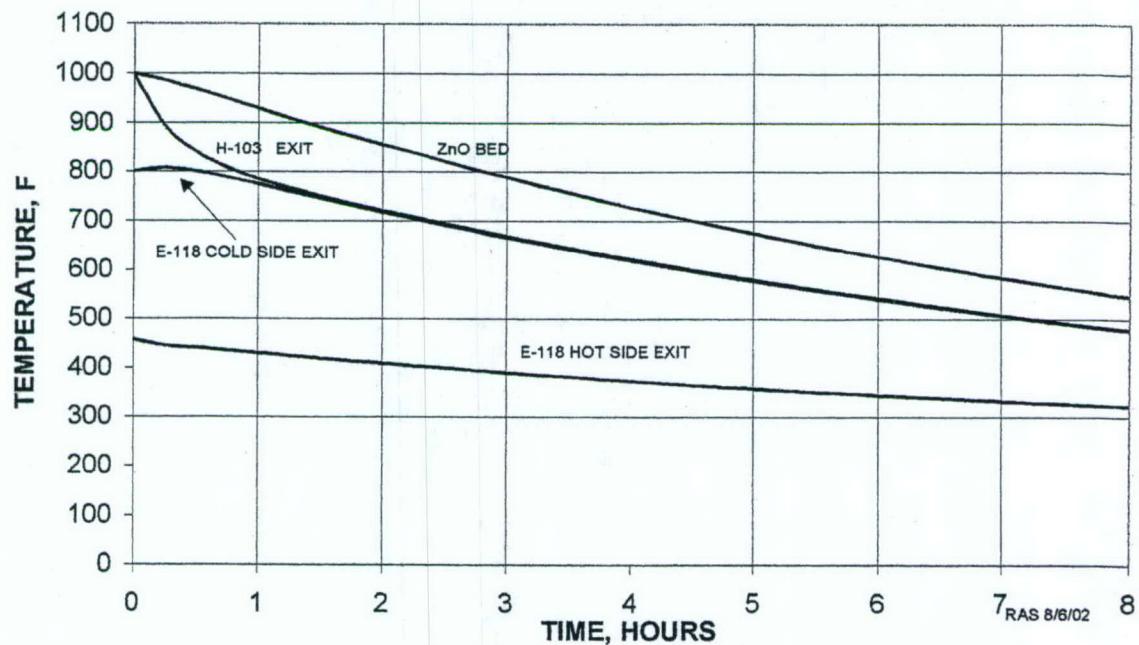
Regeneration of the ZnO bed will be accomplished in about 8 hours based on recent subscale testing. During this period the ZnS accumulated in the bed from 24 hours of operation will be oxidized. The size of the ZnO bed is based on operation for 24 hours at rated power flow on F-76 fuel that has the 1% by weight maximum sulfur level.

Step 6 In this step the ZnO bed R-102B (R-102A) and the regen loop is purged of residual oxygen with Nitrogen. The cathode exhaust supply is disconnected by closing block valve XV-913. The 40 psig nitrogen source is connected into the loop by opening block valve XV-912. Block valve XV-903 remains open, purging gases to the exhaust header. Regen flow control valve FV-914 is re-closed during this step and pressure control valve PV-915 is set to open position. After the purge, the 40 psig nitrogen source is disconnected by closing block valve XV-912. Block valve XV-903 is left open until the loop pressure reduces to 2 psig. Afterwards, block valve XV-903 is closed. This is expected to require 10 minutes based on total volume of gas of 7 Ft³, a three volume purge and a purge flow of 2.1 cfm.

Step 7 In this step the ZnO bed R-102B (R-102A) is cooled from 1000 F to 700 °F. Regen flow control valve FV-914 is set to open position. Block valve XV-903 remains closed and pressure control valve PV-915 is inactive during this step. Blower B-103 speed controller SC-904 circulates nitrogen through the loop. Heat is removed from the ZnO bed by circulating 373 lb/hr of nitrogen at near atmospheric pressure through E-118 to E-114. Heat is rejected form the nitrogen in E-114 to the water coolant system. This step is expected to take 4.5 hours as shown in Figure 2. Details of this analysis are presented in Table 2. After the ZnO bed is cooled to 700°F the temperature is maintained by continuing to circulate nitrogen at near atmospheric pressure until step 8 is initiated in preparation for switching the ZnO beds.



ZnO BED COOL DOWN AFTER REGENERATION





The energy required to maintain the ZnO bed at 700 °F can be reduced by lowering the B-103 flow rate using its variable speed drive. Table 3 shows the H-103 heater power, vessel wall heater power, the power to B-103 and the total power required to maintain 700°F at various flow rates from B-103. During this step the B-103 flow is set, the vessel heater power is set, and the H-103 heater power is controlled by the gas exit temperature from the ZnO vessel.

TABLE 3
Heater Power to Maintain ZnO at 700°F

B-103 Flow Lb/hr	H-103 Heater power, kW	ZnO vessel wall Heater Power, kW	B-105 Power, kW	Total Power, kW	EXCEL Analysis Table
373	2.2	2	3.7	7.9	3
186.5	1.3	1.5	1.0	3.8	4
93.3	1	1	0.3	2.3	5

Step 8 In this step the ZnO bed R-102B (R-102A) is pressurized from near atmospheric pressure to 920 psig with hydrogen from the electrolyzer EL-101. Hydrogen is supplied to the ZnO bed by opening block valves XV-812, XV-815 (XV-712, XV-715) and closing bleed valve XV-820 (XV-720). At the same time, the regen inlet is closed off by closing block valves XV-816, XV-817 (XV-716, XV-718) and opening bleed valve XV-818 (XV-717). The regen outlet line is closed off by closing block valves XV-802, XV-811 (XV-722, XV-724) and opening bleed valve XV-810 (XV-713). During this step flow control valve FV-834 is active and maintains flow at a defined set point. This pressurization step is completed when the reactor has reached 920 psig. This step is calculated to require 1 hr based on pressurizing 4.2 ft³ of volume inside the isolation valves and a flow of 0.3 moles/hr of available hydrogen from EL-101. This available hydrogen flow is based on operation at rated power, when the remaining 0.7 mole/hr of hydrogen output from E-101 is used in the desulfurization and hydrogenation of the F-76 fuel. The mass of hydrogen to pressurize the ZnO vessel is 0.64 lbs. This amount of hydrogen added to the vessel at a temperature of 150°F from the electrolyzer is calculated to reduce the ZnO bed temperature only about 5°F.

Step 8 is initiated 65 minutes before the required bed switchover. The Step 8 initiation point is based on the F-76 flow totalizer reaching 5294 lbs (231lb/hr x (24-1.08) hrs). This assumes the worst case in which the fuel has 1% sulfur.

When the ZnO bed is pressurized to 920 psig Step 9 is initiated.

Step 9 In this step the ZnO bed R-102B (R-102A) is reconnected to the HDS system while, at the same time, R-102A (R-102B) is taken offline. ZnO vessel R-102B (R-102A) is switched into service by opening double block valves XV-819, XV-821, XV-809, XV-813 (XV-701, XV-711, XV-709, XV-713) and closing bleed valves XV-822, XV-814 (XV-710, XV-714). At the same time, hydrogen is disconnected by closing double block valves



XV-812, XV-815 (XV-712, XV-715) and opening bleed valve XV-820 (XV-720). The estimated valve switching time is <1 minute to open various isolation valves and confirm the interlocks.

The volumes of gas in the ZnO vessel, lines within the block valves, and the volume of gas in the regen loop are listed in Table 6.

Configuration and characteristics of the ZnO vessel, insulation and ZnO bed, used in the above analysis are presented in Table 7.



TABLE 1

B6/02 16:06/ReS model B-6-02										ZnO BED HEATING BEFORE REGENERATION									
Assumptions										ZnO bed Op. Blu/hr									
ZnO bed lbs	538.6	6.4 ft ³	84.1b ft ³							Thermal mass for ZnO reactor	22052								
ZnO bed Op. Blu/hr F	0.148																		
ZnO3 support, lbs	98.8																		
ZnO3 support,Btu/hr F	0.2																		
Vessel, lbs	1085.5																		
Vessel Cp, Btu/lb F	0.11																		
E-118	E-114																		
Efficiency	0.743	0.888																	
lbs	50	8																	
Cp,Btu/lb F	0.112	0.12																	
Nitrogen flow, lb/hr	373																		
Nitrogen Cp	0.26																		
H-103 power , kW	8	NOMINAL																	
H-103 lbs	200																		
H-103 Cp,Btu/lb F	0.112																		
H-103 Input Blu/25hr	6826																		
R-102 VESSEL SURFACE	36.1																		
INSLTN K, BTU/H FT F	0.018	assume 2 ^o insulation																	
VESSEL WALL HIR, KW	2																		
RH-103 SURFACE,FT ²	8																		
B-103 TEMP RISE	120	E-118	H-103	I-103 power	ZnO bed	E-118	E-118	E-114	E-114	Q into ZnO/EAT LOSS	ZnO	ZnO	ZnO	ZnO	ZnO	ZnO	ZnO	ZnO	ZnO
T _{cold} (E-118)	To	RW	To	To	To	Thi	Thi	Thi	Thi	BTU/25 hr BTU/25 hr	BTU	BTU	BTU	BTU	BTU	BTU	BTU	BTU	BTU
Time hrs	0	246	563	700	8.0	700	700	363	363	126	0	536							
0.25	250	564	783	8.0	713	713	369	369	130	2875	549	2.875							
0.5	251	606	830	8.0	729	729	374	374	131	3602	565	6.477							
0.75	251	620	830	8.0	747	747	379	379	131	3876	582	10.353							
1	252	633	881	8.0	765	765	384	384	132	3939	599	14.292							
1.25	252	646	898	8.0	783	783	389	389	132	3905	617	18.198							
1.5	253	659	913	8.0	800	800	393	393	133	3828	633	22.025							
1.75	253	672	926	8.0	817	817	398	398	133	3731	650	25.757							
2	254	684	939	8.0	833	833	403	403	134	3628	666	29.385							
2.25	254	686	952	8.0	849	849	407	407	134	3624	682	32.908							
2.5	255	708	934	8.0	865	865	412	412	135	3420	697	36.328							
2.75	255	719	975	8.0	880	880	416	416	135	3318	711	39.846							
3	256	730	986	8.0	894	894	420	420	136	3219	726	42.865							
3.25	256	741	997	8.0	909	909	424	424	136	3123	739	45.988							
3.5	257	751	1037	8.0	922	922	428	428	137	3029	753	49.018							
3.75	257	761	1017	8.0	936	936	431	431	137	2939	766	51.956							
4	258	771	1027	8.0	949	949	435	435	138	2850	778	54.807							
4.25	258	780	1030	8.0	1018	1018	455	455	140	2375	846	70.202							
4.5	258	780	1031	8.0	1029	1029	458	458	140	2304	857	72.506							
4.75	259	788	1055	8.0	985	985	445	445	139	2602	802	60.254							
5	259	807	1034	8.0	996	996	449	449	139	2524	825	65.318							
5.25	259	815	1072	8.0	1008	1008	452	452	139	2446	836	67.827							
5.5	260	823	1030	8.0	1018	1018	455	455	140	2375	846	70.202							
5.75	260	831	1038	8.0	1029	1029	458	458	140	2304	857	72.506							
6	260	850	1046	8.0	1039	1039	460	460	140	2234	866	74.140							
6.25	261	846	1104	8.0	1049	1049	463	463	141	2167	876	76.908							
6.5	261	853	1111	8.0	1058	1058	466	466	141	2103	885	79.010							
6.75	261	860	1118	8.0	1068	1068	468	468	141	2038	894	81.050							
7	262	867	1125	8.0	1077	1077	471	471	142	1978	903	83.028							
7.25	262	874	1131	8.0	1085	1085	473	473	142	1919	912	84.947							
7.5	262	880	1138	8.0	1094	1094	476	476	142	1862	920	86.809							
7.75	262	886	1144	8.0	1102	1102	478	478	142	1806	928	88.614							

TABLE 2

Assumptions										ZnO BED COOLING AFTER REGENERATION										
ZnO bed lbs	533.6	6.4 ft ²	84 lb/ft ³	ZnO BED COOLING AFTER REGENERATION										ZnO BED COOLING AFTER REGENERATION						
ZnO bed Cp, Btu/lb F	0.149	Thermal mass for ZnO reactor										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
ZnO support lbs	93.8	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
ZnO support Btu/F	2.2	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
Vessel lbs	109.5	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
Vessel Cp, Btu/lb F	0.11	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
Effectiveness	0.43	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
lbs	50	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
Cp, Btu/lb F	0.12	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
Nitrogen flow, lb/hr	373	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
Nitrogen Cp	0.26	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
H-103 power, kW	0	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
H-103 lbs	200	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
H-103 Cp, Btu/lb F	0.12	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
H-103 input Btu/25hr	0	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
AMB TEMP, F	150	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
R-102 VESSEL SURFACE	33.1	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
INSLNK, BTU/HR FT F	0.016	assume 2" insulation										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
VESSEL WALL, HR, KW	0	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
RH-103 SURFACE FT'2	8	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
B-103 TEMP RISE	120	Btu/F										ZnO BED COOLING AFTER REGENERATION					ZnO BED COOLING AFTER REGENERATION			
Time, hrs	T ₀ (C) T _g (E-118)	E-113	H-103	ZnO bed	E-118	E-114	E-114	E-114	E-114	E-114	E-114	Q _{in} ZnO	Q _{out} ZnO	Q _{in} ZnO	Q _{out} ZnO	Q _{in} ZnO	Q _{out} ZnO	Q _{in} ZnO	Q _{out} ZnO	
Time, hrs	0	270	800	1000	0	1000	458	547	150	0	0	828	0	828	0	828	0	828	0	828
0.25	259	801	396	0.0	986	986	446	446	139	-3025	815	-3025	-5	-5	-5	-5	-5	-5	-5	-5
0.5	256	801	341	0.0	969	969	441	441	138	-3800	798	-6325	71	28.677	28.677	28.677	28.677	28.677	28.677	28.677
0.75	253	789	309	0.0	950	950	435	435	137	-4210	779	-11.135	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5
1	251	775	286	0.0	930	930	430	430	136	-4276	760	-15.411	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8
1.25	256	761	270	0.0	911	911	425	425	136	-4238	742	-19.850	-7.7	-7.7	-7.7	-7.7	-7.7	-7.7	-7.7	-7.7
1.5	256	746	251	0.0	892	892	419	419	136	-4157	723	-23.906	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5	-7.5
1.75	255	732	236	0.0	874	874	414	414	135	-4058	705	-27.864	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4	-7.4
2	255	718	222	0.0	856	856	409	409	135	-3953	688	-31.817	-7.2	-7.2	-7.2	-7.2	-7.2	-7.2	-7.2	-7.2
2.25	254	704	208	0.0	838	838	404	404	134	-3848	671	-35.965	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0	-7.0
2.5	254	691	595	0.0	821	821	399	399	134	-3743	654	-40.409	-6.8	-6.8	-6.8	-6.8	-6.8	-6.8	-6.8	-6.8
2.75	253	678	582	0.0	805	805	395	395	133	-3841	638	-43.050	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6
3	253	666	569	0.0	789	789	390	390	133	-3642	623	-46.592	-6.4	-6.4	-6.4	-6.4	-6.4	-6.4	-6.4	-6.4
3.25	252	557	554	0.0	773	773	386	386	132	-3446	607	-50.037	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2
3.5	252	545	545	0.0	758	758	382	382	132	-3350	593	-53.387	-6.1	-6.1	-6.1	-6.1	-6.1	-6.1	-6.1	-6.1
3.75	251	533	533	0.0	743	743	378	378	131	-3259	578	-56.846	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0	-6.0
4	251	519	522	0.0	729	729	374	374	131	-3169	564	-59.815	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9	-5.9
4.25	250	611	515	0.0	715	715	370	370	130	-3082	550	-62.897	-5.8	-5.8	-5.8	-5.8	-5.8	-5.8	-5.8	-5.8
4.5	249	598	500	0.0	701	701	366	366	130	-2998	537	-65.995	-5.6	-5.6	-5.6	-5.6	-5.6	-5.6	-5.6	-5.6
4.75	249	588	590	0.0	688	688	362	362	129	-2916	524	-68.811	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3
5	249	578	580	0.0	675	675	358	358	129	-2836	512	-71.647	-5.1	-5.1	-5.1	-5.1	-5.1	-5.1	-5.1	-5.1
5.25	249	568	570	0.0	663	663	355	355	129	-2758	500	-74.405	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0	-5.0
5.5	248	558	560	0.0	650	650	352	352	128	-2682	488	-77.087	-4.9	-4.9	-4.9	-4.9	-4.9	-4.9	-4.9	-4.9
5.75	248	549	551	0.0	639	639	348	348	128	-2609	476	-79.896	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7
6	247	540	542	0.0	627	627	345	345	127	-2537	465	-82.233	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
6.25	247	532	533	0.0	616	616	342	342	127	-2468	454	-84.701	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3	-4.3
6.5	247	523	525	0.0	605	605	339	339	127	-2400	444	-87.101	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1
6.75	246	515	516	0.0	594	594	336	336	126	-2334	433	-89.436	-4.0	-4.0	-4.0	-4.0	-4.0	-4.0	-4.0	-4.0
7	246	507	509	0.0	584	584	333	333	126	-2270	423	-91.706	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1
7.25	246	499	500	0.0	574	574	330	330	126	-2208	413	-93.814	-4.0	-4.0	-4.0	-4.0	-4.0	-4.0	-4.0	-4.0
7.5	245	492	493	0.0	564	564	327	327	125	-2148	404	-96.962	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9	-3.9
7.75	245	484	485	0.0	555	555	325	325	125	-2089	395	-98.150	-3.8	-3.8	-3.8	-3.8	-3.8	-3.8	-3.8	-3.8
8	245	477	478	0.0	546	546	322	322	125	-2031	386	-100.182	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7	-3.7

TABLE 3

ZnO BED HOLDING AFTER REGENERATION									
WITH FULL FLOW, 22 KW/H-103 AND 2 KW VESSEL-HEATER					WITHOUT FULL FLOW, 24 KW/H-103 AND 1 KW VESSEL-HEATER				
Assumptions									
Zinc bed lbs	538.6	6.4 ft ³	3.84 lb/ft ³						
ZnO bed Cr. Bluff F	0.149				Thermal mass for ZnO reactor	220.52			Btu/F
Al2O3 support, lbs	98.8								
Al2O3 support, Bluff F	0.2								
Vessel, lbs	1095.5								
Vessel Cr. Bluff F	0.11								
Efficiency	E-116	E-114							
Efficiency	0.743	0.888							
Ibs	50	8			Thermal mass for E-118=	6			Btu/F
C ₂ Bluff F	0.12	0.12							
Nitrogen flow, lb/hr	0.26								
Nitrogen Cr.									
H-103 power, kW	2.2 NOMINAL								
H-103 lbs	200								
H-103 Cr. Bluff F	0.12								
H-103 input Bluff 25hr	1877.15								
A MB TEMP, F	150								
R-102 VESSEL SURFACE	36.1								
INSULN K BLUHR FT/F	0.016	assume 2" insulation							
VESSEL WALL H/R, KW	2								
RH-103 SURFACE FT/2	8								
B-103 TEMP RISE	120	E-118	H-03	ZnO bed	E-118	E-114	Q into ZnO heat loss	ZNO	Heat to E-114
		T _{COOL} =T _m	T _o	T _o	T _{hi}	T _{hi}	BTU/25 hr	BTU	Btu/hr
Time, hrs	[E-118]								
0	246	583	600	2.2	700	363	363	0	536
0.25	250	582	626	2.2	697	365	365	-562	-562
0.5	250	582	638	2.2	696	364	364	-534	-534
0.75	250	581	644	2.2	696	364	364	-235	-235
1	250	581	647	2.2	696	364	364	-82	-82
1.25	250	581	648	2.2	696	364	364	-532	-532
1.5	250	581	649	2.2	696	364	364	-879	-879
1.75	250	582	650	2.2	696	364	364	0	0
2	250	582	650	2.2	697	364	364	21	21
2.25	250	582	650	2.2	697	365	365	36	36
2.5	250	582	650	2.2	697	365	365	-12	-12
2.75	250	582	651	2.2	697	365	365	532	532
3	250	582	651	2.2	697	365	365	-870	-870
3.25	250	582	651	2.2	698	365	365	1	1
3.5	250	583	651	2.2	698	365	365	-533	-533
3.75	250	583	651	2.2	698	365	365	-793	-793
4	250	583	651	2.2	698	365	365	1	1
4.25	250	583	651	2.2	698	365	365	-750	-750
4.5	250	583	651	2.2	698	365	365	41	41
4.75	250	583	652	2.2	699	365	365	-533	-533
5	250	583	652	2.2	699	365	365	-533	-533
5.25	250	583	652	2.2	699	365	365	-503	-503
5.5	250	583	652	2.2	699	365	365	-707	-707
5.75	250	584	652	2.2	699	365	365	43	43
6	250	584	652	2.2	699	365	365	-664	-664
6.25	250	584	652	2.2	699	365	365	42	42
6.5	250	584	652	2.2	699	365	365	-622	-622
6.75	250	584	652	2.2	699	365	365	1	1
7	250	584	652	2.2	700	365	365	534	534
7.25	250	584	653	2.2	700	365	365	-394	-394
7.5	250	584	653	2.2	700	365	365	1	1
7.75	250	584	653	2.2	700	365	365	-363	-363
8	250	584	653	2.2	700	365	365	-534	-534
8.25	250	584	653	2.2	700	365	365	-541	-541
8.5	250	585	653	2.2	700	365	365	1	1
8.75	250	585	653	2.2	700	365	365	-503	-503
9	250	585	653	2.2	700	365	365	1	1

TABLE 4

ZnO BED HOLDING TEMPERATURE AFTER REGENERATION WITH 1/2 B-103 FLOW AND 1 KW TO H-103 AND 1 KW VESSEL HEATER									
Assumptions	8/6/02 13:23 RAS model 8-8-02								
ZnO bed lbs	533.6 8.4 ft ³ , 8.4 lb/ft ³								
ZnO bed Ch. Bluff F	0.149								
A1203 support, lbs	93.8								
A1203 support Bluff F	0.2								
Vessel, lbs	1083.5								
Vessel Ch. Bluff F	0.11								
Ios	E-118 0.888								
Effectiveness	0.743								
Cp, Bluff F	0.12								
Nitrogen flow, lb/hr	188.5								
Nitrogen Cp	0.26								
H-103 power, kW	1.3 NOMINAL								
H-103 lbs	200								
H-103 Cp, Bluff F	0.12								
H-103 input Bluff 25hr	1108.225								
AMB TEMP F	150								
R-102 VESSEL SURFACE	38.1								
INSLNK, BLUFF FT	0.018 assume 2" insulation								
VESSEL WALL HTR, kW	1.6								
RH-103 SURFACE FT ²	8								
B-103 TEMP RISE	62.5								
B-103 OUT T _c -T _m	62.5								
Tc (E-18)									
Time, hrs									
0	189								
0.25	187								
0.5	187								
0.75	187								
1	187								
1.25	187								
1.5	187								
1.75	187								
2	187								
2.25	187								
2.5	187								
2.75	187								
3	187								
3.25	187								
3.5	187								
3.75	187								
4	187								
4.25	187								
4.5	187								
4.75	187								
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5.25	187								
5.5	187								
5.75	187								
6	187								
6.25	187								
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6.75	187								
7	187								
7.25	187								
7.5	187								
7.75	187								
8	187								
8.25	187								
8.5	187								
8.75	187								
9	187								
9.25	187								
9.5	187								
WITH 1/2 B-103 FLOW AND 1 KW TO H-103 AND 1 KW VESSEL HEATER									
ZnO bed lbs	533.6 8.4 ft ³ , 8.4 lb/ft ³								
ZnO bed Ch. Bluff F	0.149								
A1203 support, lbs	93.8								
A1203 support Bluff F	0.2								
Vessel, lbs	1083.5								
Vessel Ch. Bluff F	0.11								
Ios	50								
Effectiveness	0.12								
Cp, Bluff F	188.5								
Nitrogen flow, lb/hr	0.12								
Nitrogen Cp	0.26								
H-103 power, kW	1.3 NOMINAL								
H-103 lbs	200								
H-103 Cp, Bluff F	0.12								
H-103 input Bluff 25hr	1108.225								
AMB TEMP F	150								
R-102 VESSEL SURFACE	38.1								
INSLNK, BLUFF FT	0.018 assume 2" insulation								
VESSEL WALL HTR, kW	1.6								
RH-103 SURFACE FT ²	8								
B-103 TEMP RISE	62.5								
E-118	E-118								
T _c -T _m	T _c -T _m								
T _c (E-18)									
Time, hrs									
0	189								
0.25	187								
0.5	187								
0.75	187								
1	187								
1.25	187								
1.5	187								
1.75	187								
2	187								
2.25	187								
2.5	187								
2.75	187								
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4.75	187								
5	187								
5.25	187								
5.5	187								
5.75	187								
6	187								
6.25	187								
6.5	187								
6.75	187								
7	187								
7.25	187								
7.5	187								
7.75	187								

TABLE 5

Assumptions										ZnO BED HOLDING TEMPERATURE AFTER REGENERATION WITH H-103 FLOW AND 1 KW VESSEL HEATER									
ZnO bed lbs	536.6	6.4 ft ³	84 lb/ft ³							Thermal mass for ZnO reactor	220.62								
ZnO bed Ch. Bluff F	0.149																		
A103 support lbs	98.8																		
A103 support Bluff F	0.2																		
Vessel lbs	1065.5																		
Vessel Cp. Bluff F	0.11																		
E-118	E-114																		
Ibs	0.12	8								Thermal mass to E-118=	6								
Cp. Bluff F	0.12	0.12																	
Nitrogen flow, lb/hr	92.3									Thermal mass flow /25 hr=	6.06								
Nitrogen Cp	0.26																		
H-103 power, kW	1 NOMINAL									Thermal mass for H-103=	24								
H-103 lbs	200																		
H-103 Cp. Bluff F	0.12																		
H-103 input Bluff 25hr	83.25									HEAT REJECTION ZnO Temp from 1000 to 700	661.85								
AMB TEMP F	150																		
R-102/VESSEL SURFACE	36.1																		
INSULINK BUFFER FT F	0.018 assume 2" insulation																		
VESSEL WALL HTN, KW	1																		
RH-103 SURFACE FT F	28.5	E-113	H-103	H-103 power	ZnO bed	E-118	E-114	O min	ZnO heat loss	ZnO									
B-103 TEMP RISE	8	To=Tm	To	NW	To	To	To	BTU	BTU 25 hr BTU 25 hr	BTU									
Td (E-118)																			
Time, hrs	0	136	561	600	1.0	701	701	292	292	122	0	537							
	0.25	131	569	614	1.0	703	700	292	292	121	-208	536	-208						
	0.5	131	568	624	1.0	659	699	292	292	121	-139	536	-247						
	0.75	131	568	632	1.0	659	699	292	292	121	-86	535	-33						
	1	131	568	639	1.0	659	699	292	292	121	-45	535	-478						
	1.25	131	568	644	1.0	659	699	292	292	121	-14	535	-492						
	.5	131	568	648	1.0	659	699	292	292	121	10	535	-492	0					
	1.75	131	568	651	1.0	659	699	292	292	121	28	535	-455	0					
	2	131	568	653	1.0	659	699	292	292	121	41	535	-414	1					
	2.25	131	568	655	1.0	659	699	292	292	121	52	535	-362	1					
	2.5	131	568	657	1.0	700	700	292	292	122	60	536	-302	1					
	2.75	131	568	658	1.0	700	700	292	292	122	65	536	-237	1					
	3	131	569	659	1.0	700	701	292	292	122	69	536	-168	1					
	3.25	131	569	660	1.0	701	702	292	292	122	73	537	-95	1					
	3.5	131	569	661	1.0	701	701	292	292	122	75	537	-21						
	3.75	131	569	662	1.0	701	702	292	292	122	76	537	55						
	4	131	569	662	1.0	702	702	293	293	122	77	538	132	1					
	4.25	131	569	663	1.0	702	702	293	293	122	77	538	120	1					
	4.5	131	569	663	1.0	702	702	293	293	122	78	538	207	1					
	5	131	569	664	1.0	703	703	293	293	122	77	539	165	1					
	5.25	131	569	664	1.0	703	703	293	293	122	77	539	119	1					
	5.5	131	569	665	1.0	704	704	293	293	122	78	540	695	1					
	5.75	131	569	665	1.0	704	704	293	293	122	78	540	671	1					
	6	131	569	665	1.0	704	704	293	293	122	75	540	746	1					
	6.25	131	569	665	1.0	705	705	294	293	122	74	541	820	1					
	6.5	131	569	665	1.0	705	705	294	294	122	74	541	893	1					
	6.75	131	569	665	1.0	705	705	294	294	122	73	541	966	1					
	7	131	569	665	1.0	706	706	294	294	122	72	542	1,038	1					
	7.25	131	569	665	1.0	706	706	294	294	122	71	542	1,109	1					
	7.5	131	569	664	1.0	706	706	294	294	122	70	542	1,180	1					
	7.75	131	569	664	1.0	707	707	294	294	122	70	543	1,246	1					
	8	131	569	667	1.0	707	707	294	294	122	69	543	1,318	1					
	8.25	131	569	667	1.0	707	707	294	294	122	68	543	1,396	1					
	8.5	131	569	668	1.0	708	708	294	294	122	67	543	1,454	1					
	8.75	131	569	668	1.0	708	708	294	294	122	67	544	1,520	1					
	9	131	569	668	1.0	708	708	294	294	122	66	544	1,586	1					
	9.25	131	569	668	1.0	708	708	294	294	122	65	544	1,651	1					
	9.5	131	569	668	1.0	708	708	295	295	122	64	545	1,715	1					

TABLE 6

7/30/2002 14:32		ZNO REGENERATION - VOLUME INSIDE BLOCK VALVES		
RAS 7-15-02 PIPE - 2" TUBING .095" WALL, 1.81" ID				
VOLUME-		DIMENSIONS	LENGTH FT	VOLUME FT^3
ITEM				
VESSEL R-102A				<u>3.472</u>
LINE 7004			8	0.143
F-112	5.5" DIA x 15.75"			0.217
LINE-7005			8	0.143
F110	5.5" DIA x 15.75"			0.217
SUBTOTAL				<u>4.191</u>
 ZNO REGENERATION - VOLUME IN REGEN LOOP				
PIPE - 2" TUBING .065" WALL, 1.87" ID		ZNO REGENERATION - VOLUME IN REGEN LOOP		
VOLUME-		DIMENSIONS	LENGTH FT	VOLUME FT^3
LINE 7003				
8010			6	<u>0.114</u>
9003			10	0.191
9004			16	0.305
9005			14	0.267
9001			10	0.191
9006			7	0.134
E-114				0.086
E-118				0.996
H-103				0.333
B-103				0.188
SUBTOTAL				<u>2.805</u>

TABLE 7

7/30/2002 14:26 VESSEL WEIGHT, INSULATION SURFACE AREA AND INTERNAL GAS VOLUME			
RAS 6/25/02	HDS R-101	ZNO R-102A OR B	PREREF R-103
VESSEL	12' SCHED 80	16' SCHED 80	16'
OVERALL HEIGHT, INCH	95	94.375	94.625
VESSEL ID, INCH	11.374	14.312	14
VESSEL OD, INCH	12.75	16	16
WALL, INCH	0.888	0.844	1.000
SHELL LENGTH, INCH	73.37	77.375	79.625
SHELL WEIGHT, LBS	554.7	901.7	1088.1
HEADS, 2:1 ELP			
HEAD HEIGHT, INCH	6	7	6
HEAD STRAIGHT	2.56	2.75	1.5
HEAD THICKNESS, INCH	0.688	0.844	1.000
MATERIAL DENSITY, LB/INCH ³	0.29	0.29	0.29
HEADS (2) WEIGHT, LBS	84.4	152.5	143.6
FLANGE CLOSURE			
FLANGE OPENING DIAMETER, INCH	3.0	3.0	3.0
WEIGHT INSIDE FLANGE, LBS	13.6	10.4	7.2
minus head end out weight			
WEIGHT OUTSIDE BLIND, LBS	30.8	30.8	30.8
TOTAL VESSEL WEIGHT, LBS	683.5	1095.5	1289.8
CATALYST VOLUME, FT ³	4.4109	6.4122	6.3
CATALYST BULK DENSITY, LB/FT ³	87.21	75.00	84.10
CATALYST WEIGHT, LBS	384.67	480.92	529.83
SUPPORT VOLUME, FT ³	0.61	1.29	1.048
SUPPORT BULK DENSITY, LB/FT ³	95	95	95
SUPPORT WEIGHT, LBS	57.95	122.55	99.56
TOTAL VESSEL + CATALYST + SUPPORT	1126	1699	1839
INSULATION SURFACE AREA			
INSULATION THICKNESS, INCH	2	2	2
MEAN DIAMETER, INCH	14.75	18	18
SHELL SURFACE AREA, FT ²	23.6	30.4	31.3
HEADS (2) SURFACE AREA, FT ²	4.0	5.7	4.7
MEAN SURFACE AREA, FT ²	27.6	35.1	36.0
FOR HEAT LOSS ANALYSIS			
INTERNAL GAS VOLUME			
VOLUME IN HEADS, FT ³	0.524	0.566	0.683
VOLUME IN SHELL, FT ³	4.314	7.204	7.093
CATALYST BULK VOLUME, FT ³	4.4109	6.4122	6.3
CATALYST BULK DENSITY, LB/FT ³	87.21	75	84.1
CATALYST MATL. DENSITY, LB/FT ³	341.0	341.0	308.0
CATALYST VOID FRACTION	0.370	0.395	0.373
CATALYST MATL. VOLUME, FT ³	2.779	3.679	3.850
CATALYST GAS VOLUME, FT ³	1.632	2.533	2.350
SUPPORT VOLUME, FT ³	0.61	1.29	1.048
SUPPORT BULK DENSITY, LB/FT ³	95	95	95
SUPPORT MATL. DENSITY, LB/FT ³	151.5	151.5	151.5
SUPPORT VOID FRACTION	0.373	0.373	0.373
SUPPORT MATL. VOLUME, FT ³	0.382	0.809	0.657
TOTAL NET GAS VOLUME, FT ³	1.877	3.472	3.189

Appendix Number	Topic and Description	Training Module
A15		Classroom #5 Ship #1, 4



FuelCell Energy

SPECIAL SAFETY FEATURES

Final Design Review
January 30, 2003
Contract No. N00014-00-C-0169

- Relief device (valve or burst disk) protecting all vessels & lines
- Automatic alarms & shutdowns on out-of-limit process conditions
- Fail position on all valves for emergency shutdown
- Activation of emergency shutdown on any condition preventing normal shutdown
- Limit switches on all on-off valves
- Independent start burner management system to code standards
- Differential pressure control and relief on fuel cell fuel manifold seals to avoid seal leakage
- Equipment grounded to avoid static generated sparks
- Ups power to all subsystem controllers
- Backup power supply for key equipment during emergency shutdown

Appendix Number	Topic and Description	Training Module
A16	Fire suppression - system description	Classroom #5 Shipboard #1, 4

4.20 FIRE SUPPRESSION

A fire suppression system is included in the SSFC power plant to protect the equipment in the MBOP enclosure. The fire suppression system uses water misting. Water misting nozzles (4-6) are strategically located within the MBOP enclosure. Activation of the fire suppression system is initiated by high temperature or rapid rise in temperature by sensors located at the inlets to the process air blower B-101 and the MBOP ventilation blower B-104. Activation of the system directs 1.3 gpm of water plus nitrogen at 75-85 psig to each of the misting nozzles. The configuration of a spray nozzle is shown in Figure 4.20-1. A schematic of the system is shown in Figure 4.20-2. The system water piping is pressurized up to the water zone valve and the nitrogen piping is non-pressurized until activation of the system. In the event of a fire, the water mist controller detects an alarm signal from a rate compensated heat detector. The initial response of the water mist controller is to activate the high pressure solenoid valve, which releases nitrogen from the high pressure nitrogen cylinders. The nitrogen pressure is stepped down from 2300 psig to 100 psig and directed to the nitrogen zone valve and low pressure solenoid valve. A few seconds after detection of an alarm, the controller activates the low-pressure solenoid valve that allows both the nitrogen zone valve and water zone valve to open. Water and nitrogen flow to the nozzles where they are mixed to produce a fine water mist. The control panel provides a cyclic release of the water mist, which includes 50 seconds of water mist followed by 40 seconds off. After three cycles there is a 180 second stand-by with the misting system off.

The system will be located off-module. The off-module equipment assembly shown in Figure 4.20-3 is 50" wide by 50" long and 72 " high. The control panel is shown in Figure 4.20-3. The alarm panel for the system is shown in Figure 4.20-4.

The system described above is a SECURIPLEX system proposed Sanders Fire & Safety located in Mechanicsville, NY . A similar HI-FOG® system has also been proposed by Marioff Inc. located in Linthicum , MD. Both systems are presently under evaluation.

FIGURE 4.20-1 WATER MIST NOZZLE

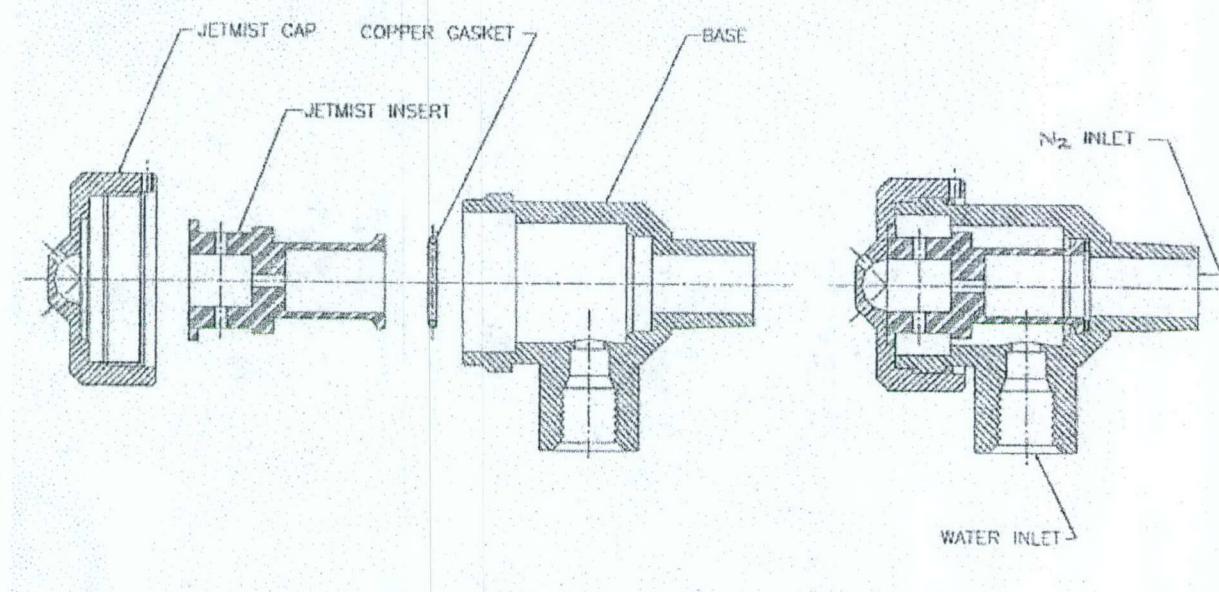


FIGURE 4.20-2 FIRE SUPPRESSION SYSTEM

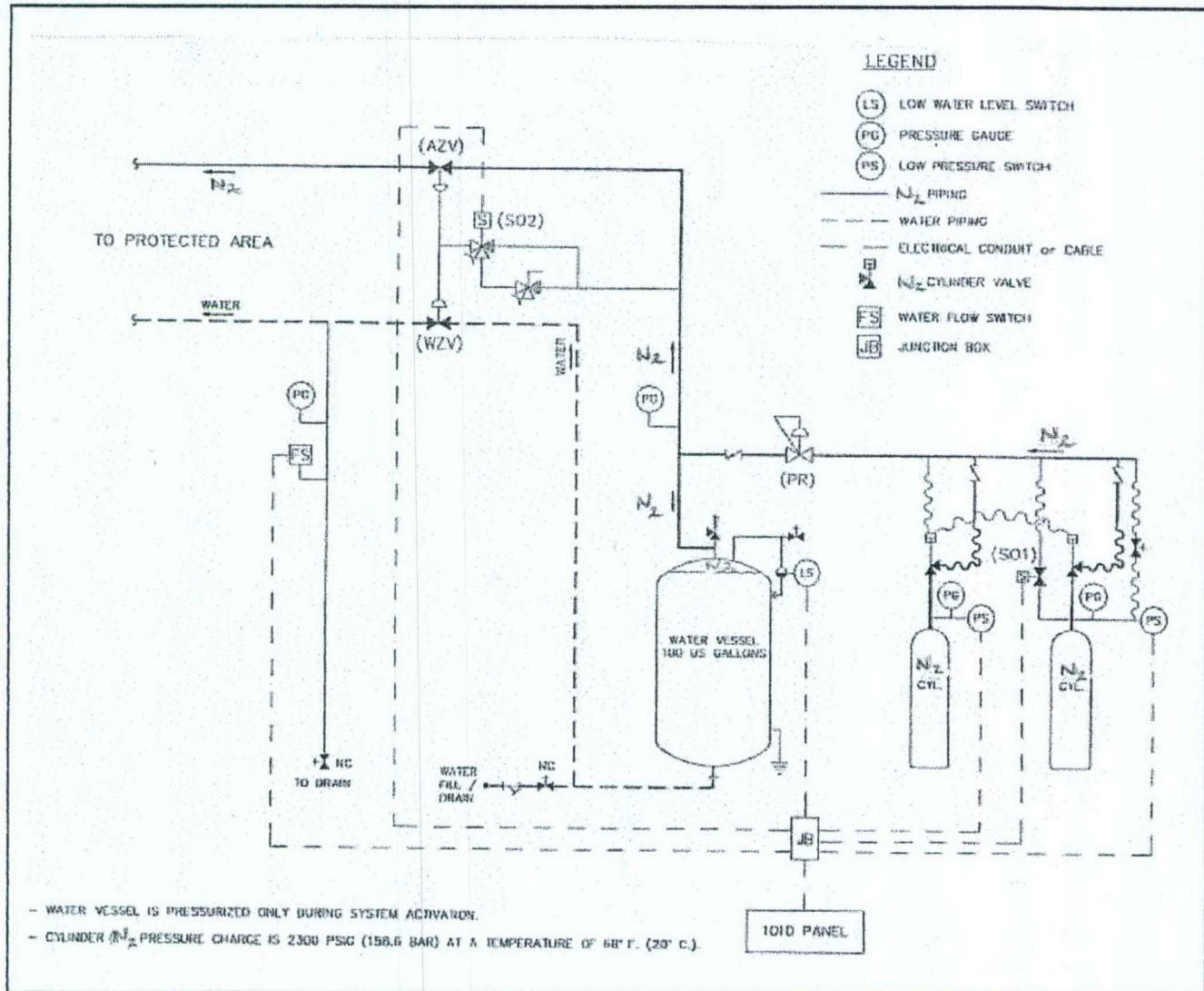


FIGURE 4.20-3 FIRE SUPPRESSION SYSTEM ASSEMBLY

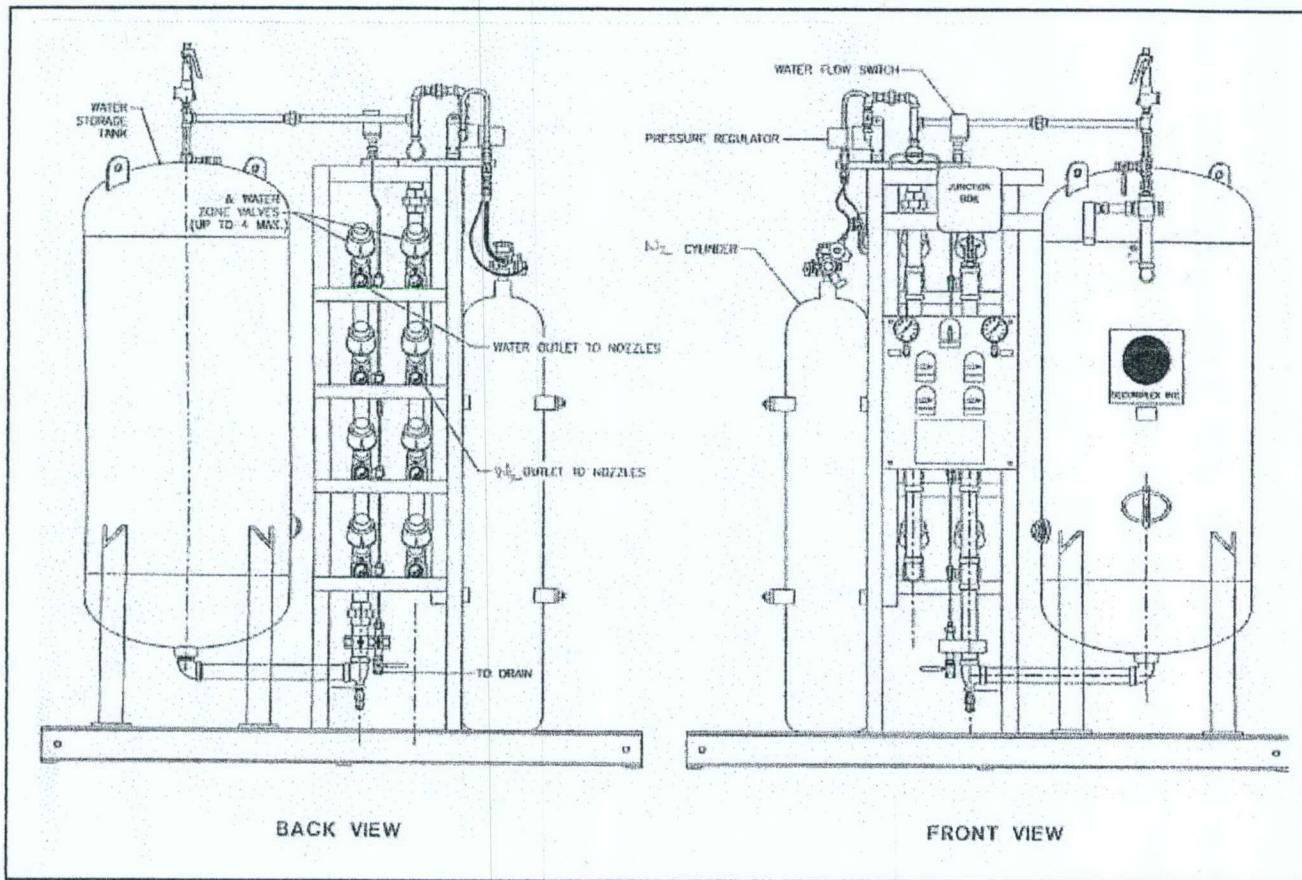
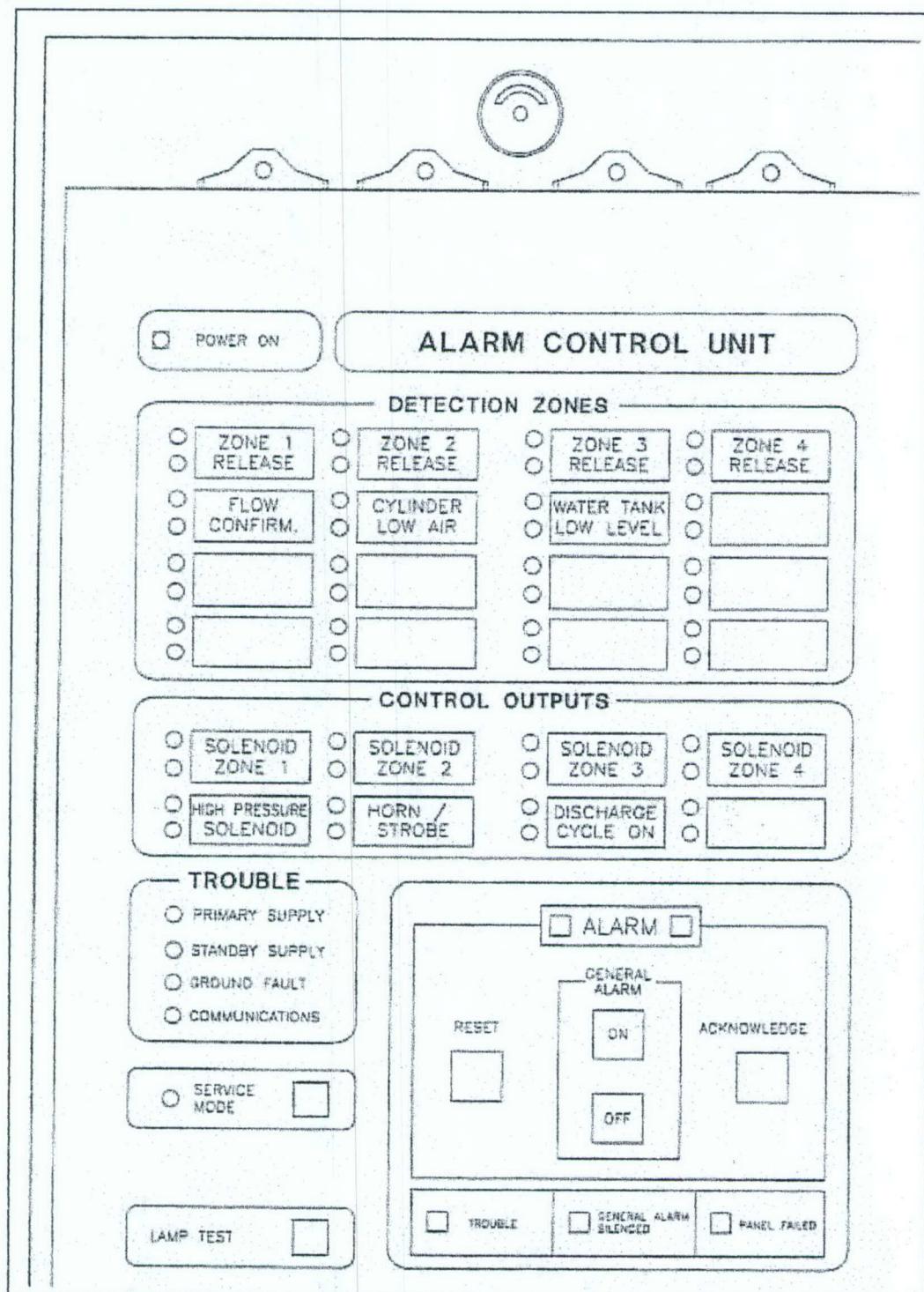


FIGURE 4.20-4 FIRE SUPPRESSION SYSTEM ALARM PANEL



Appendix Number	Topic and Description	Training Module
A17	Combustible Gas Monitoring in the SSFC	Shipboard #4



Combustible Gas Monitoring in the Ship Service Fuel Cell

Four combustible gas detectors are used in the SSFC. Combustible gas is monitored at two locations within the fuel cell compartment and at two locations within the mechanical balance-of-plant (MBOP). Within the MBOP combustible gas is monitored at the module blower B-104 suction intake and at the process air blower B-101 suction intake.

The combustible gas detectors check for total combustible gas including methane, CO, and H₂. Each detector will be calibrated based on hydrogen. The resolution for each detector is 300 ppmv based on hydrogen. The PLC will alarm (High Alarm) at 400 ppmv. The High High Alarm Limit is set for 50% Lower Explosion Limit (LEL) of hydrogen, where hydrogen has an LEL of 4% by volume. An occurrence of High High Alarm in either the MBOP or the fuel cell compartment will cause the plant to initiate an emergency shutdown.

For combustible gas detection within the MBOP enclosure, the system would consist of two (2) each gas detection probes to be installed within the MBOP enclosure and wired to electronics modules that will be mounted outside of the MBOP environment. For combustible gas detection within the fuel cell compartment, the system would consist of two (2) each gas detection probes/transmitter modules to be installed in a NEMA 4 enclosure with sample draw components. This enclosure will also be mounted outside of the MBOP environment.

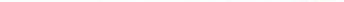
Appendix Number	Topic and Description	Training Module
A18	Hazard and Operability Study	Classroom #5 Shipboard #4

L CELL ENERGY Inspection Guide and Checklist

Title:	Fuel Cell Inspection Guide and Checklist
Application:	FCE Sub-Megawatt 300A Units

Cell A-300: 8
Customer: Coast Guard

Cell Unit #: 8
Location: Cape Cod

Current Revision Verified By (Signature): 

Revision	Date	Approved By	Pages	Inserted By

FUEL CELL ENERGY Inspection Guide and Checklist

SUMMARY AND NOTES OVERVIEW

SUMMARY: This overview provides a quick index of each Section and applicable Notes.

Section	Summary	Notes
Periodic Inspection	Periodic inspection items behind each door panel and overall plant. Periodic visual inspections of the power plant should be performed at regular intervals to check for conditions that may adversely impact its operation. This section describes the visual checks to be performed behind each panel.	

APPENDIX AND TABLES

Section	Summary	Notes
Appendix 1	Items to check during a general inspection of the unit.	

FUEL CELL ENERGY Inspection Guide and Checklist

PERIODIC INSPECTION

SECTION SUMMARY: Periodic Inspection behind each door panel and overall plant. Periodic visual inspections of the power plant should be performed at regular intervals to check for conditions that may adversely impact its operation. This section describes the visual checks to be performed behind each panel.

PRECAUTIONS:

This maintenance activity is generally performed while the plant is energized and operating. Use extreme caution. To avoid the risk of a shock during these inspections, do not enter the enclosure of any electrical cabinet where warning labels indicate hazardous electrical energy sources exist.

Lethal AC and DC voltages are present behind several hinged and removable panels. DO NOT open or remove the panels unless you are trained, qualified, and are wearing proper personal protective equipment (PPE) in accordance with federal, state, local, and site-specific electrical safety regulations.

KEEP ALL PANELS LOCKED IN PLACE EXCEPT DURING SERVICING.

The fuel cell module current posts maintain lethal DC voltage even after all external power has been disconnected and the fuel cell stack is cooled to ambient temperature.

When entering any power plant compartment, review and abide by site-specific safety regulations and procedures as required.

Wear personal protective equipment (PPE) appropriate for the task being performed based on federal, state, local and site regulations and procedures.

Use standard safety procedures for handling and storing compressed gas when dealing with the gas (nitrogen and anode cover gas) cylinders.

No smoking, sparks, or open flames.

Do not press Emergency Shutdown (ESD) Button unless authorized to do so, or unless an emergency condition requires a manual shutdown of the system.

Do not block or obstruct any air openings. Maintain spacing around the DFC A300 to provide clearance for the intake and discharge of required air.

Keep the area surrounding the power plant clear of all combustible materials.

Maintain a minimum five-foot clearance around the perimeter of the power plant for maintenance access.

The DFC A300 power plant is designed to be controlled from a computer within the unit, or from a remote location. Equipment could start or stop anytime the power plant is enabled.

To help safeguard personnel from the unexpected startup of equipment or release of hazardous energy, federal standards (29 CFR, Parts 1910.147 and 1910.269) regarding the use of Lockout/Tagout/Tryout practices and procedures are applicable at all times.

PAY ATTENTION TO WARNING LABELS.

Do not store materials on the roof. Follow all applicable OSHA fall protection standards when working six feet or more above ground.

The exhaust stack and vent pipes located on the roof are extremely hot. DO NOT TOUCH.

FUEL CELL ENERGY

Inspection Guide and Checklist

Sub-Step	Task	Detail
1.01 ACTION <input type="checkbox"/>	Ensure all ventilation airways are unblocked (All Panels)	<ul style="list-style-type: none"> • Fuel Prep Compartment Outside Air Louvers (Above Doors 18 and 19) • Fuel Prep Compartment Exhaust Fans Louvers (Above Door 11 enclosed in hood) • Module Compartment Outside Air Louvers (Above Door 7 and 8 enclosed in hood) • Module Compartment Exhaust Fans Louvers (To the side of Doors 20, 21 and 22) • Transformer Vault/WTS Compartment Roof Ventilation Fan (Roof) • Transformer Vault/WTS Compartment Roof Outside Air Louver (Above Door 6)
1.02 ACTION <input type="checkbox"/>	Ensure no protective covers for the Emergency Shutdown (ESD) Buttons are broken	ESD buttons are in the following locations: <ul style="list-style-type: none"> • On the Main Control Panel behind Door 1 • Between Doors 1-Main Control Panel and 2-Power Conditioning Unit Access • Between Doors 11-Mechanical Balance of Plant and 12-Desulfurizer Change out Access
1.03 ACTION <input type="checkbox"/>	Ensure utility supply valves for gas and water connections are fully open and piping has no leaks	Both supply and drain lines should be checked including the HVAC drain.
1.08 ACTION <input type="checkbox"/>	Check UPS operating normally (Door 1-Main Control Panel)	UPS Display should indicate: Md: Auto St: ON Line Acvolin 120 ± 2 V M2-B4-6 (upper right hand corner) <p>If any error messages are displayed, notify the Site Maintenance Supervisor: Critical = Red LED is constantly lit and audible alarm is a constant beep. Non-Critical = Red LED is blinking and audible alarm is an intermittent beep.</p>
1.09 ACTION <input type="checkbox"/>	Check central air conditioner/heater thermostat for proper settings (Door 1-Main Control Panel behind HMI Panel)	Fan in Auto, air conditioner setpoint at 80°F, heat setpoint at 50°F, and temperature control in Auto.
1.10 ACTION <input type="checkbox"/>	Perform general inspection (Door 1-Main Control Panel)	Refer to Appendix 1
1.14 ACTION <input type="checkbox"/>	Check Inverter Control Panels for fault conditions. (Doors 3 and 4-Power Conditioning Unit)	If fault conditions exist, notify Site Maintenance Supervisor.
1.15 ACTION <input type="checkbox"/>	Perform general inspection of main circuit breakers, connections and wiring. (Door 5-Main Power Plant Circuit Breakers)	Refer to Appendix 1

FUEL CELL ENERGY

Inspection Guide and Checklist

1.16 ACTION <input type="checkbox"/>	Slide out water treatment system salt tanks and perform general inspection of compartment. (Door 6-Water Treatment System-Salt Tank)	<ul style="list-style-type: none"> Refer to Appendix 1 Look for leaks on the water treatment system. Check salt tank level and add if necessary. Verify safety latches closed. Ensure float switches are lying flat on top of the salt.
1.17 ACTION <input type="checkbox"/>	Check 480V Distribution Panel breakers not tripped and in the correct position. (Door 7-Balance of Plant Distribution Panel)	If tripped, check for possible cause. If cause cannot be initially determined then breakers can be closed once to ensure condition no longer exists.
1.18 ACTION <input type="checkbox"/>	Perform general inspection of VFD section. (Door 8-Motor Drive Access)	Refer to Appendix 1
1.20 ACTION <input type="checkbox"/>	Perform general inspection of PLC cabinet (Door 9-PLC Access)	All VFD displays should indicate RUN and a non-flashing number, or STOP. Any other words or letters in the display are indicative of a problem and should be investigated. Refer to Appendix 1
1.22 ACTION <input type="checkbox"/>	Verify heat trace breaker CB-3 and UPS Breaker CB-2 not tripped (Door 9-PLC Access)	
1.23 ACTION <input type="checkbox"/>	Perform general inspection of air system compartment (Door 10-Fresh Air System Access)	Refer to Appendix 1 Listen for any abnormal sounds from the recycle blower or ventilation fans indicative of bearing distress.
1.24 ACTION <input type="checkbox"/>	Check level on automatic lubricators for recycle blower bearings (Door 10-Fresh Air System Access)	If level is less than ¼ capacity, then replace. When replacing the lubricator, mark the level on the casing with the current date. Lubricators should be set at level 8 with a 1/8" Allen wrench.
1.29 ACTION <input type="checkbox"/>	Perform general inspection of mechanical balance of plant compartment (Door 11-Mechanical Balance of Plant Access, Doors 12 and 13 Desulfurizer Change out Access, Door 16-Compressed Gas Cylinder Access, Door 17-Natural Gas Shutoff Valve Access, and Door 19-Preconverter Access)	Refer to Appendix 1 Listen for any abnormal sounds from ventilation fans indicative of bearing distress.
1.30 ACTION <input type="checkbox"/>	Verify AT-230, Exhaust Stack LEL Detector energized and indicating properly. (Door 11-Mechanical Balance of Plant Access)	<ul style="list-style-type: none"> Normal Flow-Green LED indicator illuminated on Pump Module %LEL should indicate less than 25% No water present in gas filter enclosure. If water is present, drain water, and verify loop seal not blocked.
1.31 ACTION <input type="checkbox"/>	Check compartment heater thermostat for proper setting. (Door 11-Mechanical Balance of Plant Access)	Compartment heater should be set to 50°F
1.33 ACTION <input type="checkbox"/>	Verify Anode Cover Gas Bottle Pressure, PI-427 is greater than 800 PSIG (Door 11-Mechanical Balance of Plant)	If pressure is low, then replace the bottle.
1.36 ACTION <input type="checkbox"/>	Verify six nitrogen bottles are operating properly and all isolation valves HV-403A through HV-403F are open. (Door 16-Compressed Gas Cylinder Access and 17-Natural Gas Shutoff Valve Access)	

FUEL CELL ENERGY

Inspection Guide and Checklist

1.37	ACTION <input type="checkbox"/>	Perform general inspection of the mechanical balance of plant (Door 17-Natural Gas Shut Off Access)	Refer to Appendix 1
1.38	ACTION <input type="checkbox"/>	Verify Nitrogen Cylinder Pressure, PI-415, is greater than or equal to 800 PSIG (Door 17-Natural Gas Shut Off Access)	If pressure is not within specification, replace nitrogen bottles. Cylinder pressure must be >300 PSIG as a permissive for plant startup.
1.40	ACTION <input type="checkbox"/>	Verify Natural Gas Pressure, PI-203, is 9 ± 1 PSIG (Door 17-Natural Gas Shut Off Access)	If pressure is not within specification, notify Site Maintenance Supervisor.
1.41	ACTION <input type="checkbox"/>	Perform general inspection (Door 18-Sample Bulkhead Panel Access)	Refer to Appendix 1 Verify that all sample port caps are in place and all sample port isolation valves are closed.
1.43	ACTION <input type="checkbox"/>	OBSERVE Desulfurizer Afterfilter Differential Pressure, PDI-214. (Door 18-Sample Bulkhead Panel Access)	If the differential pressure is greater than 1", make arrangements to replace the filter.
1.44	ACTION <input type="checkbox"/>	Perform general inspection (Door 19-Preconverter Access)	Refer to Appendix 1
1.46	ACTION <input type="checkbox"/>	Perform general inspection of the DFC module compartment (Door 20-Fresh Air System Access)	<ul style="list-style-type: none"> • Refer to Appendix 1 • Listen for any abnormal sounds from the fresh air blower or ventilation fans indicative of bearing distress. • Verify all open-end piping has a cap installed.
1.48	ACTION <input type="checkbox"/>	Perform general inspection (Door 21-DFC Module Access)	Refer to Appendix 1
1.50	ACTION <input type="checkbox"/>	Slide out water treatment system and perform general inspection of compartment. (Door 22-Water Treatment System)	<ul style="list-style-type: none"> • Refer to Appendix 1 • Look for leaks on the water treatment system. • Verify all open-end piping has a cap installed. • Verify safety latches closed
1.52	ACTION <input type="checkbox"/>	Perform general inspection (Door 23-UPS Access Panel)	Refer to Appendix 1

FUEL CELL ENERGY

Inspection Guide and Checklist

Mechanical Equipment-Prime Movers (Pumps, Compressors, Fans, Engines, Turbines, etc.)	
Leaking seals	
Loose support bolts; cracked foundation pedestal	Anchorage problems can be caused by, and result in, equipment vibration
Loose or missing equipment guards	Personnel safety hazard. Also may result in equipment damage due to casual contact.
Dirty or clogged filters	Clogged filters can increase operating temperature, reduce system or component performance, generate flow-induced vibration, or cause cavitation, etc.
Leaking oil or grease	
Reduced discharge pressure	May be indicative of equipment problem or reduced net positive suction head due to flow restriction.
Mechanical Equipment-Valves, Dampers, etc.	
Missing or loose hand wheels or lever arms	
Bent, damaged, or corroded components	
Broke, disconnected, or out of adjustment linkages	
Packing leakage	
Blocked vents	Can cause reduced component or system performance, high operating temperatures, or flow induced damage.
Worn safety valve vent pipes	Leaking safety valves can result in steam cutting of seats and increased corrosion of valve discharge piping.
Mechanical Equipment-Tanks, Heat Exchangers, Filters, Strainers, etc.	
Improperly sealed manways or hatches	
Plugged or clogged atmospheric vents	May result in reduced venting, condensation accumulation, or over pressurization
Corrosion at base	
Foul odors	Indicative of biological activity which may cause fouling and corrosion
Corrosion at seams	Weld heat affected zones and bimetallic welds are particularly susceptible to degradation
Mechanical Equipment-Piping	
Corrosion products seeping through insulation	Tell-tale sign of pipe external corrosion
Corroded hangers	
Pinhole leaks or seepage	
Missing or not fully engaged flange nuts, studs, or bolts	Particularly in vibrating systems or in systems recently modified or subject to maintenance
Excessive sweating or condensation collecting on pipes	A common cause for external corrosion of piping and accumulation of water on equipment surface below the piping.
Leaking on threaded connections	
Excessive pipe vibration or pipe movement	Flow- or mechanically-induced vibration will encourage fatigue crack growth, particularly at welds and stress concentrations.
Damaged or missing thermal or anti-sweat insulation	Encourages sweating on cold systems and releases heat to the ambient on hot systems. Heat losses from a hot system may reduce plant efficiency, and accelerate aging of secondary components.
Cracked elastomer joints	Indicative of excessive movement between mating components (settlement) or aging of elastomer.

FUEL CELL ENERGY

Inspection Guide and Checklist

APPENDIX 1

Mechanical Equipment-General	
Leaking components	Leaks are indicative of problems (leakage sources), but also create stressors (corrosive fluid) for other components.
Chemical spillage or usage	Chemical storage or handling areas are likely locations of damage. Ground and floor spills can percolate through soils or construction joints and damage buried components.
Excessive vibration	A particular concern at stress concentrations (welds, termination points, bolt thread, etc.) where cracks can initiate. Possible causes include: Failed hanger/support, harmonic driving forces, oscillating control valves, rotating equipment misalignment, unstable flow (cavitation, high turbulence, etc.), rotating equipment imbalance.
Missing or loose bolts or other fasteners	Particularly prevalent in vibrating systems or areas recently modified or subject to maintenance
Unusual odors	A change in odors may indicate chemical usage or spill, biological activity, overheating of electrical components, or overheating of mechanical components.
Unusual temperatures	Low temperatures can cause freeze-thaw damage, reduce metal toughness properties, or damage polymers. High temperatures can accelerate the degradation of many materials and produce unexpected thermal expansion loads.
Corrosion	Watch for susceptible materials exposed to corrosive fluids and for dissimilar metals contacting each other in an electrically conductive fluid (electrolyte). The presence of corrosion products may be indicative of metal consumption elsewhere in the system.
Unusual or changing sounds	<ul style="list-style-type: none"> • "Flowing gravel" noise-Cavitation at pump suction or downstream of flow restrictions can result in aggressive damage of pump internal, pipe, etc. • Whining noise-May indicate problems with rotating equipment such as: bearing wear, misalignment, imbalance, inadequate or contaminated lubrication, etc. • Banging noise-May indicate inappropriate check valve operation. • Increase in flow sounds-May indicate increased turbulence or flow velocity, a change in operating mode, or development of a flow obstruction. Such conditions may cause erosion damage, loss of flow head, fretting and denting of tubes, or system vibration. • Hissing noise-Air leakage • Crackling noise-High voltage discharge • Buzzing/humming noise-Ionization or high current loads • Clanging noise-Loose parts • Tapping noise-Unstable instruments, clamps, pilot valves, etc. • Squeaking noise-Inadequate lubrication of moving parts or loose or dry belts • Change in sound character-An increase, decrease, or change in sound character can be an important indicator.

FUEL CELL ENERGY
Inspection Guide and Checklist

Electrical Equipment-Cables, Conduit, Cable Trays, Enclosures, Buses, Terminations, Splices; etc	
Broken flexible conduit	Most prevalent in vibration regions, high traffic areas, climbing areas and, recent construction sites.
Damaged conduit	Most prevalent in vibration regions, high traffic areas, climbing area and, recent construction sites.
Missing or damaged termination box covers; loose or damaged cable trays; loose or damaged conduit connectors	Most prevalent in vibration regions, high traffic areas, climbing areas and, recent construction sites.
Soft, discolored, or embrittled insulation materials	Local thermal damage of cable jackets may be indicative of conductor damage, splice overheating, splice overloading or external heat source influence. Widespread damage can result from a cable or neutral overload or from a hot environment. Soft, discolored, or embrittled cable jackets also may be indicative of chemical attack.
Inadequate ventilation	Accelerates thermal aging and condensation build-up
Mechanical damage to cables	Likely locations of damage include splices, penetrations, saddles, cable ties, sharp bends, conduit edges, tool drop areas, ladders and vibrating equipment.
Slimy surface	Possible in continuously damp areas and in direct buried conditions. May indicate biological damage potential. Potential confusion with identification between a lubricant or slime can be resolved with a dry out test that eliminates biological slime.
Traces of soot	May indicate electrical arcing
Electrical arc damage	Potential to occur near areas of high electrical stress, particularly in high voltage systems.
Cracked insulators	Particularly in high traffic or construction areas. Leads to reduce cooling efficiency and elevated temperatures.
Electrical Equipment-Motors	
Dirty or clogged filters, screens, or louvers	Leads to reduce cooling efficiency and elevated temperatures.
Missing ground straps	Personnel safety hazard. Also, may cause stray current corrosion.
Excessive noise or vibration	Indicative of misalignment, or loose or degraded anchorage. Can cause damage to bearings or anchorage.
Loose or missing foundation bolts or nuts	Possible cause and/or result of a vibration problem
Electrical Equipment-Breakers and Panels	
Mounting hardware loose or missing	
Loose, discolored or burnt connections	
Dirty or blocked air screens, filters, or louvers; dirt or debris in or on cabinet; panel cooling fan not operating properly	Lack of ventilation and build-up of contamination may cause malfunction or thermal damage of instruments. Dirt or dust intrusion may damage or seize moving parts.
Doors/covers do not close or latch properly	
Burnt or discolored paint	Discolored coatings may be indicative of overheating.
Hot spots	Loss of internal flux shielding
Excessive humming	Loss of wedging
Damaged insulators and bushings	
Electrical Equipment-Heat Tracing	
Missing or damaged	Likely causes are construction activities or movement of equipment in the area

Original dated March 2003

Table 1

FUEL CELL ENERGY

Inspection Guide and Checklist

Heated components continuously warm or cold	May be indicative of a failed power supply or thermostat. Can result in freeze/thaw damage or accelerated degradation caused by overheating.
Instrumentation and Controls-Instruments, Controllers or Transmitters	
Broken or damaged gauges or sight glasses	Pegged or damaged gauges can be indicative of pressure spikes or over pressurization.
Leaking vent or drain caps	Frequent calibration drifts can be indicative of aggressive environments, vibration, pressure spikes, or voltage spikes.
Out of calibration equipment	
Inconsistent or erroneous reading on local indicators	
Damaged or missing seals or cover plates	
Loose or missing mounting hardware	
Rusty, dirty, or unreadable sight glasses	
Erratic or unexpected controller output	
Instrumentation and Controls-Instrument Tubing	
Loose, leaking or misaligned tubing connectors	
Bent, crimped or damaged tubing	Most prevalent on exposed tubing, at sharp corners, in climbing areas, and in tool drop areas.
Excessive tubing vibration	Vibration can be pressure-induced or caused by a failed clamp. Fatigue damage can result in failures at stress concentrations.
Signs of air leakage	
Instrumentation and Controls-Switches/Annunciators/Alarms	
Broken or missing lights or lenses	
Broken or askew switches/push-buttons	
Supports for Piping, Equipment, Conduit, Cable Trays, Instruments, etc.	
Missing or loose bolting	Most frequently found in vibrating systems or systems recently modified or subject to maintenance.
Bent strut or other support member	Indicative of excessive loading, possibly caused by thermal expansion, water hammer, pressure transient, or external mechanical force.
Slide plate interference or misalignment	Can result in excessive forces cause by thermal expansion. Can be detected by lack of any indication of any indication of slide plate movement, e.g., protective coatings intact at interface between slide plate and guides.
Loose at floor, wall, or component	May indicate cyclic loading or vibration. Possible locations include rotating equipment, thermally cycled piping and equipment, and piping subjected to cyclic pressure transients.
Bent hanger rods	
Loose anchor bolts	
Bent, damaged, painted or rusted snubber shafts/supports	
Bottomed or topped spring and snubber positions	

Original dated March 2003

Table 1

Appendix Number	Topic and Description	
A19	FCE Inspection Guide and Checklist – Maintenance logging and reporting document	Classroom #6 Lab #5 Shipboard #5

FUELCELL ENERGY
Danbury, CT

**HAZARD AND
OPERABILITY STUDY
of the**

**SHIP SERVICE FUEL CELL
PROJECT**



SEPTEMBER 2001

JACOBS
ENGINEERING
Engineers and Constructors

JEG Project No. 67-S339-00

Table of Contents

- 1.0 MANAGEMENT SUMMARY
- 2.0 BACKGROUND
 - 2.1 Project Description
 - 2.2 Previous Reviews
- 3.0 FINDINGS
 - 3.1 HAZOP Action Items
- 4.0 HAZOP REVIEW PROCESS
 - 4.1 HAZOP Method
 - 4.2 Hazard Risk Index
 - 4.3 Team Members
 - 4.4 Meeting Dates
- 5.0 APPENDIX
 - A. HAZOP Logsheets
 - B. HAZOP Action Items
 - C. Piping and Instrument Diagrams
 - D. Acronyms

1.0 MANAGEMENT SUMMARY

This report documents the hazard and operability (HAZOP) study performed on the Ship Service 625 kw Fuel Cell Project for Fuel Cell Energy during June through September 2001. The HAZOP was led by Jacobs Advanced Technology (JAT), but was a team review with technical specialists with FuelCell Energy, Inc. (FCE).

The purpose of the HAZOP was to review the current stage of design of the project, and to identify any operating or failure scenarios that could produce unacceptable health, safety, and environmental conditions. In addition, the HAZOP was to identify an unacceptable scenarios that would result in operating problems or damage to equipment.

The process was divided into thirty-nine (39) specific study nodes and one general study node. The scope of each study node is described in the HAZOP logsheets (Appendix A) and illustrated on the P&IDs (Appendix C). The HAZOP primarily reviewed revision B of the P&IDs, but a few of the revision C P&IDs were also reviewed.

As a result of this study, the HAZOP study produced 297 action items. These action items and their background are contained with the HAZOP logsheet record provided in Appendix A, but a summarized list of all action items is contained within Appendix B.

2.0 BACKGROUND

2.1 Project Description

The project consists of engineering, designing and fabricating a 625 kw power generating fuel cell system for U.S. Navy ships that uses NATO F-76 (diesel) fuel. The fuel is to be desulfurized in the process, then reformed to a methane rich stream, and then supplied to the anode side of the fuel cell. The anode exhaust is dried then reacted with air to supply oxygen and carbon dioxide to the cathode side of the fuel cell. Hydrogen for the desulfurizing process is supplied by the anode exhaust and a water electrolyzer.

The entire process, controls and power conditioning equipment are to be contained within a single skid package with certain overall dimensional and weight limitations.

2.2 Previous Reviews

In December 2000, a preliminary failure modes and effects analysis (FMEA) review was performed on the process design. This task was performed by FuelCell Energy under separate cover. However, this review was not significantly referenced during this HAZOP.

3.0 FINDINGS

3.1 HAZOP Action Items

The HAZOP identified situations of concern that were unacceptable with the current level of safeguards as provided by the existing proposed design and procedures. In order to mitigate these concerns, the HAZOP team generated 297 action items. The basis of these action items is provided in the HAZOP logsheets in Appendix A, but a summarized list of the action items is provided in Appendix B.

4.0 HAZOP REVIEW PROCESS

4.1 HAZOP Method

The HAZOP method used to identify the unacceptable hazards was as follows:

1. **Selection of a study node:** A set of equipment, line or operating step was selected, whose function could be easily defined for the team to focus their review.
2. **Statement of the design intention:** The function or purpose of the equipment in terms of flow, temperature, pressure, composition, level, etc. was stated.
3. **Selection of a process parameter from the design intention:** Parameters such as flow, temperature, and pressure were selected for the team to more narrowly focus their review. Other parameters such as composition, level, maintenance, safety, start-up, shut-down were considered if they were applicable. (Note: If a correction to the P&ID was required and it was not based upon a safety concern, then the action item generated was placed under the "P&ID" guideword).
4. **Selection of a guide-word:** A standard HAZOP guideword was selected:
 - No or Not
 - More
 - Less
 - Reverse
 - As Well As (in addition)
 - Other than (instead)
5. **Combination of the process parameter with a guide-word to create a deviation:**
The HAZOP guideword was then combined with the parameter selected in step 3.
 - No Flow, More Flow, Less Flow, Reverse Flow, Misdirected Flow
 - Higher Pressure, Less Pressure, No Pressure (vacuum)
 - Higher Temperature, Lower Temperature
6. **Determination if there is a potential cause for that deviation:** Possible causes were then determined. For instance the valve is closed, the valve is open, the pump fails, the heater fails, the controller fails, etc.
7. **Consequences as a result of the cause are determined:** The consequence is described without regards for existing safeguards or protective devices. As a general guideline, causes were only found within the study section. However, the resulting consequences were considered throughout the process.

8. **Safeguards that prevent or minimize the consequence are stated:** Alarms, valve position indication, relief valve, operating procedures, administrative procedures, maintenance, etc.
9. **Analysis of the risk:** The severity and frequency of the consequence occurring with the existing safeguards in place was considered. If the risk was unacceptable, an action item was generated.
10. **All parameters and deviations considered:** Steps 4 through 9 were repeated for each parameter. A different parameter was then chosen, step 3, and the process was repeated.
11. **Review performed for all study nodes:** After all of the parameters had been reviewed within a study node, then another study node was selected (step 1), and the entire process was repeated.

4.2 Hazard Risk Index

Scenarios identified by the HAZOP study that could lead to detrimental health, safety, environmental or system damage effects were assigned a hazard risk index based upon U.S. Military Standard MIL-STD-882D. The hazard risk index was calculated by first assigning a hazard category to the consequence and then a probability level based upon how frequent the consequence were to occur with the existing level of safeguards. The hazard category and probability level were then applied to a matrix table that determined the hazard risk index. The hazard risk index, the probability level and the hazard risk index tables are below.

The determination of the hazard category was primarily based upon the consequence description. Examples of consequences specific to the ship service fuel cell process have been included in the table below to aid in consistent application of the risk system.

HAZARD CATEGORIES			
Category	Description	Mishap Definition	Example
I	Catastrophic	Death, system loss, or severe environmental damage.	Large destructive fire
II	Critical	Severe injury, severe occupational illness or major system damage.	Small fire, unit shutdown for significant duration.
III	Marginal	Minor injury, occupational illness, or minor occupational illness or less than minor system or environmental damage.	Reduced run length, catalyst damage, equipment damage.
IV	Negligible	Less than minor injury, less than minor occupational illness or less than minor system or	Poor operating control, recoverable operating problems. Unit

	environmental damage.	shutdown.
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Examples of the probability of single failures typical to the ship service fuel cell process have also been included in the table below to aid in consistent application of the risk system. However, the final determined hazard probability level was based upon the combination of the probability of the cause occurring, and the described consequence occurring along with the probability of failure of the listed safeguards.

HAZARD PROBABILITY LEVELS			
Level	Description	Individual Unit Application	Example
A	Frequent (>0.1/year)	Likely to occur frequently.	Single thermocouple failure.
B	Probable (0.1 – 0.01/year)	Will occur several times in the life of an item.	
C	Occasional (10^{-2} – 10^{-3} /year)	Likely to occur sometime in the life span of the item.	Control valve or XV fails to its failure mode.
D	Remote (10^{-3} – 10^{-6} /year)	Unlikely, but possible to occur in the life of an item.	Control valve fails opposite its failure mode. PLC failure.
E	Improbable (<10 /year)	So unlikely assumed that occurrence may not be experienced.	

The hazard category and hazard probability level values were then applied to the table below to determine the hazard risk index.

HAZARD RISK INDEX

Probability	HAZARD CATEGORIES			
	Catastrophic I	Critical II	Marginal III	Negligible IV
A	1	3	7	13
B	2	5	9	16
C	4	6	11	18
D	8	10	14	19
E	12	15	17	20

The suggested criteria for the calculated hazard risk index was as follows:

Hazard Risk Index	Suggested Criteria
1 – 5	Unacceptable
6 – 9	Undesirable (ONR 334 decision required)
10 – 17	Acceptable with review by ONR 334
18 - 20	Acceptable without review

4.3 Team Members

The HAZOP team members were as follows:

FuelCell

Sandors Abens	Project Manager
George Steinfeld	Mgr. System Development, Fuel Processing
Hossein Ghezel-Ayagh	Senior Scientist
Bob Sanderson	Sr. Systems Engineer
Bill Keil	Mechanical Engineer
Franklin Horowitz	Sr. Chemical Engineer
Michael Lukas	Systems Engineer

ADI

Tony Sliwa	Safety Engineer
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Jacobs Advanced Technology / Jacobs Engineering Group

Kenny Kalmbach	Principal Process Engineer
Mark Eidson	HAZOP Facilitator

4.4 Meeting Dates

The HAZOP team met on the following dates:

June 18-22, 25-29
July 23-27, 30, 31
August 1-3
September 5-7, 10-13

5.0 APPENDIX

A. HAZOP Logsheets

The HAZOP logsheets for study nodes 1 through 16 (including "General") were provided to the project on August 9, and study nodes 17 through 39 on September 14, so that they could be used for action item tracking. The logsheets were not revised as a result of the HAZOP after those respective dates to prevent multiple copies of the electronic file from being circulated. However, during the HAZOP of the remaining study nodes or the discovery of typographical errors, the logsheets should be revised as follows:

HAZOP Study Node	Addendum
General	Add action item "G.13.3: Eliminate manual block valves on either side of filters in non-liquid service, since the entire system will have to be cooled and purged anyway for maintenance."
2	Add the following to the Design Intent: "Note – When study node 2 was reviewed, the startup feed was downstream of P-101. When the Start Burner was reviewed in study node 24, the startup fuel feed line was considered to be upstream of P-101."
5	Revise the Design Intent from "Alloy 625 grade 2" to "Alloy 625 grade 1"
13	Change action item that follows action item 13.16.3 from 13.6.4 to 13.16.4.
17	Change action item 32.17 to 32.17.1.

STUDY NODE LIST

Node #	Study Node Title	Equipment	P&ID s
1	Fuel Feed	F-102, P-101	5, 10
2	Fuel to H-102 for Startup	-	5, 10
3	HDS Regen Heat Exch. – Fuel Side	E-111	10, 16
4	Fuel Evaporator (Fuel Side) and Bypass	E-105	16, 6
5	HDS Reactor	R-101, F-109	6, 7
6	ZnO Reactors – Normal operation	R-102A	7, 8
7a	ZnO Reactors – Regen: offline	R-102B	8, 9
7b	ZnO Reactors – Regen: depressurize	R-102B	8, 9
7c	ZnO Reactors – Regen: N2 purge	R-102B	8, 9
7d	ZnO Reactors – Regen: N2 heat	R-102B, B-103, H-103, E-114	8, 9
7e	ZnO Reactors – Regen: burn	R-102B, B-103, H-103, E-114	8, 9
7f	ZnO Reactors – Regen: N2 purge	R-102B	8, 9
7g	ZnO Reactors – Regen: cool	R-102B, B-103, E-114	8, 9
7h	ZnO Reactors – Regen: standby	R-102B	8, 9

Node #	Study Node Title	Equipment	P&ID s
7i	ZnO Reactors – Regen: pressurize	R-102B	8, 9
8	Coolant System	V-104, P-104, F-108, E-112, WT-103	20
9	Module Ambient Cooler	E-117	
10	Fuel Cell Stacks and Hot Box	DFC-101A/B, M-101	15
11	HDS Regen Heat Exch. – H2 & Fuel Side	E-111	7, 8, 10
	Fuel Condenser – Fuel Side	E-110	10
	Desulfurizer Tank, Relief and Water Out	S-102	10
12	H2 From Desulfurizer Tank to E-102	-	10, 16
	HDS Recycle Compressor and N2	B-105	10
13	Electrolyzer (vendor package)		19, 22, 10
14	Fuel from Desulfurizer to E-102 and to H-102	-	10, 16, 14
15	Prereformer Inlet Preheater & Bypass	E-102	16, 12
16	Prereformer	R-103, F-116	12
17	Prereformer Regeneration	R-103	12, 13, 14
18	Turbine Generator, Processed Gas Heater and Anode Gas to Fuel Cell Stack	TG-101, E-101	12, 13, 14, 16
19	Anode Exhaust		
	Anode Exhaust Regenerator – Recycle Side	E-108	14, 18
	Anode Exhaust Condenser	E-109	18
20	Condensate Tank	S-101	18
21	Anode Recycle Blower	B-102, E-108	18
22	Prereformer/Anode Startup		12, 15, 16, 18
23	Process Air to E-104	F-101, F-107, B-101	6, 16
	Air Preheater (Air Side) and Bypass	E-104	16
	Air to Hot Box and Start Burner	-	16, 15, 14
24a-h	Start Burner Air Blower, Start Burner, Catalytic Oxidizer and Cathode Gas to Fuel Cell Stack	F-106, B-106, H-102, H-101	14
24a	Startup to heat system. (Raw fuel burned in H-102).		
24b	Startup to continue to heat system. (Desul fuel burned in H-102).		
24c	Normal Operation		
24d	Normal with ZnO regen (H2S into H-102). (Desul fuel burned in H-102).		
24e	Sustaining (same as Normal)		
24f	Sustaining with ZnO regen (H2S into H-102). (Desul fuel burned in H-102).		

Node #	Study Node Title	Equipment	P&ID s
24g	Shutdown/standby (desulfurized fuel burned in H-102)		
24h	Final shutdown (raw fuel burned in II-102)		
25	Condensate Pump & Coarse Filter	P-102, F-103	18, 16
	Condensate Heater & Bypass – Water Side	E-116	16, 19
26	Degasifier and Water Vapor	WT-101	19, 18
	Water Treatment Cooler	E-115	19
	Water Treatment Pump	P-105	19
	Demineralizer	WT-102, F-104	19
27	Boiler Feed Pump	F-104, P-103	19, 16
	Feedwater Heater and Boiler	E-107, E-106	16, 11
28	High Flow Fuel Eductor	EJ-101	12, 11, 16
	Low Flow Fuel Eductor	EJ-102	12, 11, 16
29	Hot Box Cathode Exhaust	H-104, E-101, 102, 103, 105, 106, 107, 116, 104	15, 16
30	Nitrogen	-	5
31	CO2/Fire Suppression	V-104	5
32	Relief Vent Header	S-103	23
33	HDS Reactor (Polishing)	R-101B	17
34	ZnO Reactor (Polishing)	R-102C	17
35	HDS Reactor Loop Startup (including electric heaters on each reactor)	R-101A/B, R-102A/B/C, H-103, E-118, E-114	sketches
36	HDS Recycle Startup Loop	E-105, B-105, E-111, E-110, S-102	10
37	Turbine Generator Cooling	E-119	13
38	Gas Monitor		5
39	Normal and Emergency Shutdown		

B. HAZOP Action Items

G.2.1: Define instrumentation for motor status, running, etc.
G.4.1: Determine which actuated isolation valves (XV's) should not have a manual over-ride feature and be AUTO only because of consequences if improperly operated.
G.5.1: Ensure that the fire scenario calculation is considered as an overpressure scenario for all pressure vessels.
G.5.2: Specify every heat exchanger in the process with a fouling factor on each side.
G.5.3: Evaluate if the temperature control valves on the coolant line to heat exchangers can be replaced with a fixed device to balance the flow between all coolant users. (P&ID D-100-020)
G.5.4: Review all thermocouples in the process and determine which ones should be duplex (triplex?).
G.7.1: Route the relief device on the discharge of the positive displacement blowers (B-103, B-105) to the relief header so that the blower will not be over heated.
G.8.2: Confirm with equipment vendors what is the maximum external pressure rating for equipment, and have this value documented on the vessel nameplate.
G.10.1: Develop detailed procedures for the start-up and shutdown for the entire process.
G.10.2: Perform a HAZOP review on the start-up and shutdown of the unit.
G.11.1: Identify process connections for running the PAC test.
G.12.1: Determine how the unit should operate during a loss of power emergency shutdown. What systems should be depressurized and by what means. Are new XV's to atmospheric vents required?
G.12.2: Generate a normal and emergency shutdown procedure. Consider how the H2S, liquid fuel and gaseous hydrogen will be purged and disposed. (P&ID D-100-010).
G.13.1: Determine how failure detection and correction will be performed for all process equipment and controls. Identify critical pieces of equipment and position them for easier access if possible.
G.13.2: Evaluate which systems are going to have maintenance performed on them, while other systems within the unit are operating.
G.13.3: Eliminate manual block valves on either side of filters in non-liquid service, since the entire system will have to be cooled and purged anyway for maintenance.
G.14.1: Develop operating and maintenance procedures for the entire process (Fuel Cell and balance of plant).
G.14.2: Remove hose connections on vents and drains throughout the process and replace with plugs.
1.1.1: Change the HDS Regenerative Heat Exchanger E-111 cold side and hot side design pressure from 1000 to 1050. (P&ID D-100-010)
1.1.2: Provide redundancy for the Desulfurized Fuel Tank S-102 level control. (P&ID D-100-010)
1.1.4: Evaluate if the Fuel Pump P-101 discharge flow element (FE-501) can be eliminated, by using the electronic stroke control output from the metering pump to indicate the flow rate. (P&ID D-100-005)
1.1.5: Ensure that the manual block valve on the fuel line supply (V-505) is accessible. (P&ID D-100-005)
1.2.3: Consider interlocking XV-528 to the HDS Reactor (R-101) pressure and temperature to prevent filling the system with fuel during startup. (P&ID D-100-005, (P&ID D-100-006)
1.2.5: Evaluate if the hydrogen recycle (HDS Recycle Compressor P-105) and the Electrolyzer (EL-101) should be shutdown on loss of fuel flow for an extended duration. (P&IDs D-100-010, D-100-023, D-100-005)
1.2.8: Move PT-513 as close to the suction of the Fuel Pump P-101 to ensure fuel supply pressure at the pump suction and the Fuel Filter F-102 is not plugged. (P&ID D-100-005)
1.3.1: Interlock XV-528 (fuel isolation valve to HDS Regen Exchanger E-111) to close when the Fuel Pump (P-101) is not in operation. (P&ID D-100-005)
1.4.1: Confirm that the Start Burner H-102 package includes an automated fuel isolation valve, that will be closed when the burner is out of operation. (P&ID D-100-014)
1.9.1: Develop an operating procedure that defines the frequency and type of raw fuel analysis. (P&ID D-100-005).
1.9.3: Develop a maximum water and chloride content specification for the raw fuel supply. (P&ID D-100-005).
1.9.4: Provide a sample point between raw fuel supply block valve V-505 and the enclosure. (P&ID D-100-005).
1.10.1: Add a drip pan in the enclosure to handle 33 gallons (capacity of fuel oil storage tank in the enclosure) minimum. Provide a low point drain. (P&ID D-100-005).
1.11.1: Provide high point vent on the fuel line to enable the removal of air, and or make the startup line to H-102 higher than the normal operating line. (P&ID D-100-005).
1.14.1: Review the need and location for raw fuel supply XV-515, and possible interlocks. (P&ID D-100-005).

1.14.2: Add XV-528 to downstream of Fuel Pump P-101 to HDS Regen Heat Exchanger E-111. (P&ID D-100-005).
1.14.3: Remove the differential pressure transmitter (DPI-512) for the Fuel Filter F-102 and the manual isolation valves (V-506, V-507). (P&ID D-100-005)
2.1.1: Determine how the Fuel Pump P-101 will be controlled during startup operation. Consider pressure control at the burner (spillback to pump suction?) and simultaneous flow requirements to the HDS Reactor. (P&ID D-100-005)
2.1.2: Develop operating procedures for the pulsation dampener on the discharge of the Fuel Pump P-101. (P&ID D-100-005).
2.1.4: Interlock the XV-516 (fuel to H-102) to close when the Start Burner H-102 is shutdown to prevent fuel into the Burner without ignition. (P&ID D-100-005).
2.2.5: Ensure that the Start Burner H-102 has adequate controls to purge un-burned fuel prior to ignition restart. (P&ID D-100-014).
2.3.2: Design the raw fuel pressure to the H-102 Start Burner to be lower than the desulfurized pressure in S-102. (P&ID D-100-014)
2.3.4: Add a manual sample connection to the liquid fuel side of Desulfurized Fuel Tank S-102. (P&ID D-100-010)
2.3.5: Consider using the liquid desulfurized fuel in Desulfurized Fuel Tank S-102 to fire the Start Burner H-102 for a short period at the end of the startup to ensure that the S-102 system is purged of any raw fuel that may have leaked into it. (P&ID D-100-010)
3.10.1: Ensure that the HDS Regenerative Heat Exchanger E-111 is leak tested with helium or hydrogen rather than nitrogen to ensure integrity. (P&ID D-100-010)
3.10.2: Investigate if the HDS Regenerative Heat Exchanger E-111 needs to be pressure tested at 1.5 times the design pressure. (P&ID D-100-010)
4.6.2: Configure the PLC to shutdown the unit if a low HDS Reactor R-101 bed temperature is indicated. (P&ID D-100-006)
4.6.3: Evaluate if the PLC should switch the temperature control of E-105 from TE-1605 to the HDS Reactor bed temperature TE-603 if TE-1605 fails. (P&ID D-100-006, D-100-016)
4.6.4: TV-1605 (E-105 temperature control) should fail in its last position. (P&ID D-100-016)
5.9.2: Specify pre-sulfided catalyst for the HDS Reactor R-101. (P&ID D-100-006)
5.14.4: Determine how catalyst will be removed and replaced in the HDS Reactor R-101. Consider how top access will limit reactor height. (P&ID D-100-006)
5.16.1: Investigate if the HDS Reactor R-101 catalyst presents a static charge and/or dust explosion hazard, and develop appropriate procedures. (P&ID D-100-006)
5.17.1: Remove the differential pressure transmitter (DPI-612) for the HDS Filter F-109 and the manual isolation valves (V-606, V-605). (P&ID D-100-006)
5.17.2: Review the design of all relief valve piping configurations. Are rupture discs required, are bleeds (with excess flow valve) between the rupture disc and relief valve required or is pressure indication adequate.
6.2.1: Evaluate hazards when hydrogen or H ₂ S is relieved into the Relief KO Pot and vented to the atmosphere, and consider an inerting nitrogen purge of the relief system.
6.4.1: PLC interlock the bleed valves on double block and bleed systems, so that the bleed valve cannot be opened (including manually) unless both block valves are closed.
6.13.3: Determine how sorbent will be removed and replaced in the ZnO Reactor R-102A/B. Consider how top access will limit reactor height. (P&ID D-100-007, D-100-008)
6.14.1: Remove the DPT-720 and block valves V-705 and V-706 on the ZnO Filter F-110, and DPT-820 and block valve V-805 and V-806 on the ZnO Filter F-111. (P&ID D-100-007, D-100-008)
6.14.2: Remove the DPT-712 and block valves V-709 and V-708 on the ZnO Filter F-112, and DPT-812 and block valve V-813 and V-814 on the ZnO Filter F-113. (P&ID D-100-007, D-100-008)
6.14.3: ID Relocate the pressure indication PT-702 from downstream of F-112 to upstream, and PT-801 from downstream of F-113 to upstream. Use a chemical seal on PT-702 and PT-801 so that they do not plug with sorbent. (P&ID D-100-007, D-100-008)
7a.4.2: Evaluate the need for a screen on the feed inlet of the ZnO Reactors (R-102A/B) to prevent solids pluggage during sudden depressurization (reverse flow of solids could plug piping and valves). (P&ID D-100-007, D-100-008)
7b.4.1: Investigate where the ZnO Reactor R-102A/B depressurized gas is to be sent because this gas will poison the Catalytic Oxidizer H-101 and damage the cathode in the Fuel Cell. (Consider depressurizing reactors from the bottom, so that the depressurized gas will contain less H ₂ S). (P&ID D-100-008)
7b.7.1: Program the depressurization step in the ZnO Reactor R-102A/B regeneration to be based upon both time and pressure. (P&ID D-100-007, D-100-008)
7b.7.2: Change the piping spec up to and including XV-826, XV-827 and to H-102 block valve V-1403 to NA09 to prevent overpressuring the piping during ZnO Reactor R-102A/B regeneration depressurization. (P&ID D-100-007, D-100-008)
7b.10.1: Investigate attenuating the noise created by the large pressure drop across the XV-826 valve during ZnO Reactor (R-102A/B) regeneration depressurization. (P&ID D-100-008)

7b.11.1: Change the ZnO Reactor R-102A/B depressurizing valve to XV-826 rather than both XV-802 and XV-722. Make XV-802 and XV-722 standard on/off valve. (XV-826 can be an on/off valve rather have multiple functions as XV-802 and XV-722 would have to be). (P&ID D-100-007, D-100-008).
7b.11.2: Evaluate collecting the ZnO depressurizing stream and recycling it back into the process. (P&ID D-100-007, D-100-008).
7c.2.1: Establish a flowrate and time (duration) for the nitrogen purge of the ZnO Reactors (R-102A/B) during their regeneration. (P&ID D-100-009)
7c.2.2: Establish a flowrate and time (duration) for the nitrogen purge of the ZnO Reactors (R-102A/B) during their regeneration. (P&ID D-100-009)
7c.2.3: Provide a manual sample on the nitrogen/cathode exhaust line upstream of the pressure control valve PV-915, to verify adequate purging. (P&ID D-100-009)
7c.2.4: Ensure that the PLC includes a time and nitrogen flowrate for the nitrogen purge step of the ZnO Reactors (R-102A/B)
7c.2.7: Evaluate increasing the design pressure of the entire ZnO Reactor R-102A/B regeneration loop including ZnO Regen Heater H-103 and the ZnO Regen Boost Blower B-103 and piping to 50 psig.
7c.2.8: Evaluate operating the nitrogen heating step at 35 psig to increase mass flow and reduce purge and heating time. (P&ID D-100-007, D-100-008, D-100-009)
7c.2.9: Add a pressure regulator to the nitrogen supply before manual valve V-901, to reduce the pressure to 40 psig. (P&ID D-100-009)
7c.2.10: Evaluate removing the rupture disc (PSE-908) on the ZnO Regen Heater (H-103) because it is in clean service. (This includes removing the bleed line and excess flow valve SP-402). (P&ID D-100-009)
7d.2.2: Delete the ZnO Regen Boost Blower (B-103) discharge valve XV-905. (P&ID D-100-009)
7d.2.4: Evaluate if an XV valve (XV-916) should be added to the cathode exhaust line to the ZnO Reactor R-102 regen loop, and the check valve (CK-901) removed. (P&ID D-100-009)
7d.5.3: Consider dual thermocouples (TE-907) on the outlet of the ZnO Regen Heater (H-103). (P&ID D-100-009).
7d.12.1: Relocate the relief device (PSE-908/PSV-918) for the ZnO Regen Heater (H-103) from the heater shell to the inlet of the ZnO Regen Recuperator E-118. (Nozzles on equipment will not be required and the relief device will be at a cooler temperature.) (P&ID D-100-009)
7d.12.1: Add a check valve in the nitrogen supply to the ZnO Reactor regen system. (P&ID D-100-009)
7e.4.1: Evaluate the need for a double block and bleed on the hydrogen pressurization valves (XV-715, XV-815) into the ZnO Reactors R-102A/B. (P&ID D-100-007, D-100-008)
7e.5.1: Provide an oxygen analyzer in the ZnO Regen Boost Blower B-103 discharge and use it to adjust/reset the amount of cathode exhaust gas into the ZnO Reactor (R-102B) regen system to prevent a runaway reaction or poor burning occurring between thermocouples during the regen "burn" step. (P&ID D-100-007, D-100-008, D-100-009).
7e.5.3: Evaluate the design at a maximum (regen "burn" step) 1600°F operating temperature of the ZnO Reactors R-102A/B. (P&ID D-100-007, D-100-008)
7e.5.5: Program the PLC to shutdown the ZnO Regen Boost Blower (B-103) if the ZnO Reactor (R-102A/B) is at a high-high temperature. (P&ID D-100-007, D-100-008, D-009).
7e.5.7: Evaluate if nitrogen flow (XV-912 opens) should be interlocked to open on high-high temperature in the ZnO Reactor (R-102A/B). (P&ID D-100-009).
7e.10.2: Evaluate making the ZnO Regen Booster Blower (B-103) a variable speed drive and control the speed based upon ZnO Reactor (R-102A/B) regen "burn" temperature. (P&ID D-100-015)
7e.10.3: Provide a raw liquid fuel totalizer so that it can be used with the % sulfur content analysis (manual PLC input) to calculate the amount of sulfur loading on the ZnO Reactor R-102A/B and initiate the regeneration step on loading rather than time. (P&ID D-100-005).
7e.12.1: Confirm the noise level of the ZnO Regen Boost Blower B-103, and mitigate unacceptable noise levels. (P&ID D-100-009)
7e.14.1: Verify the maximum temperature and temperature profile of the ZnO Reactor R-102A/B exit gas temperature during regeneration ("burn" step), and evaluate the design temperatures of the regen system (E-118, E-114 and piping). (P&ID D-100-007, D-100-008, D-100-009)
7e.14.2: Provide dual thermocouples for the ZnO Reactors (R-102A/B) for reliability. (P&ID D-100-007, D-100-008)
7f.9.1: Evaluate if the ZnO Regen Cooler (E-114) and the ZnO Regen Boost Blower (B-103) and piping should be purged during the N2 purge step of the ZnO Reactor regeneration. (P&ID D-100-009)
7i.10.1: Define the duration of every step in the batch regen cycle to ensure that the regen process can be completed within 24 hours. (P&ID D-100-007, D-100-008, D-100-009)
8.2.2: Provide a high pressure alarm to the discharge of the Coolant Pump (P-104). (P&ID D-100-020)
8.5.2: Ensure that the PCS has a loss of coolant flow or a high temperature alarm that can be indicated in the PLC.
8.5.3: Evaluate if the temperature control valve (TV-2001) on the sea water into Sea Water Exchanger E-112 can be eliminated. (P&ID D-100-020).
8.5.4: Review the coolant system for adequate contingency/design safety factor. Max the flow through Sea Water Exchanger (E-112) with the Coolant Pump Design (P-104). (P&ID D-100-020).
8.5.5: Specify the Sea Water Exchanger (E-112) with a fouling factor. (P&ID D-100-020). FCE says No

8.7.2: Ensure that the sea water supply is filtered to prevent plugging the relief valve (PSV-2008) on the Sea Water Exchanger and plugging the exchanger. (P&ID D-100-020).
8.7.3: Evaluate if the relief valve (PSV-2008) on the Sea Water Exchanger is required. (P&ID D-100-020).
8.10.1: Ensure that access is provided to re-fill (manual valve V-2004) the coolant system during unit operation. (P&ID D-100-020)
8.11.1: Finish defining the needs and design of the Coolant Water Treatment Unit (WT-103). (P&ID D-100-020).
8.16.1: Ensure that the orientation Sea Water Exchanger E-112 is such that the plates can be removed for maintenance while the exchanger is in its installed position. FCE said NO
8.17.1: HAZOP the Coolant Water Treatment Unit (WT-103) when details are available. (P&ID D-100-020)
8.18.1: Remove the temperature element TE-2001 downstream of the Coolant Pump P-14, and use the temperature element (TE-2006) on the outlet of E-112. Renumber TE-2006 to TE-2001. (P&ID D-100-020)
8.18.2: Delete the differential pressure transmitter (DPT-2005), because the Coolant Filter F-108 will be on routine maintenance. (P&ID D-100-020).
8.18.3: Provide a block valve on the discharge of the Coolant Filter F-108 for routine maintenance. (P&ID D-100-020).
8.18.4: Evaluate why the design pressures on the Sea Water Exchanger are not the same (50 psig/100 psig), and why the thermal relief (PSV-2008, 50 psig) is not the same as the cold side design pressure of 100 psig. (P&ID D-100-020).
9.5.4: Determine the high temperature limits for motors, electrical equipment and instruments in the enclosure, and evaluate the need for higher temperature limits on motors, electrical equipment and instruments as needed. (P&ID D-100-006).
9.5.5: Review the need for the Module Ambient Cooler E-117 on the demonstrator unit, if 85°F ambient air is adequate to cool the module with the Process Air Blower (B-101). (P&ID D-100-020). TDB What does 85 F air have to do with it, why not 122 F air.
10.1.1: Evaluate how to handle high flow from the anode flow control valve or the Expander Turbine Expander TG-101 bypass. (P&ID D-100-013).
10.2.1: Evaluate if the 12" Fuel Cell DFC-101B cathode exhaust valve (XV-1518) can be deleted. (Can a positive pressure be placed on the Fuel Cell Stack to prevent the reverse flow of exhaust gas containing sulfur into the Fuel Cell during startup, or can the valve be a check valve?). (P&ID D-100-015)
10.3.2: Evaluate if raw fuel can be avoided for startup (system heatup) to prevent equipment corrosion, SO2 emissions and the potential for sulfur poisoning of the fuel cells.
10.5.2: Provide a high temperature alarm on the Fuel Cell DFC-101A cathode discharge (TI-1502). (P&ID D-100-015).
10.5.3: Program the PLC to drop the unit load on high temperature in the Fuel Cell DFC-101B. (P&ID D-100-015).
10.11.1: Provide combustible gas detectors inside of the Hot Box M-101 at the anode inlets, to detect hydrogen/ methane leaks. (P&ID D-100-015).
10.12.1: Add a pressure transmitter of the Start Burner (H-102) exhaust to compare to the cathode exhaust pressure, and use this information to control the Process Air Blower (B-101) to keep the cathode pressure higher and thus preventing SO2 from getting into the Fuel Cell stack cathode side. (P&ID D-100-015)
10.12.2: Review startup strategy and establish a standard startup procedure for the Fuel Cell Stacks (DFC-101A/B). (P&ID D-100-015).
10.14.1: Add pressure indication on anode exhaust of DFC-101B, and on one side of each of the differential pressure transmitters (DPT-1513, DPR-1504, DPT-1515). (P&ID D-100-015).
10.16.1: Evaluate if increasing the discharge pressure of Anode Recycle Blower B-102 can eliminate the 4" bypass line around the reforming unit (RU) in the Fuel Cell Stacks DFC-101A/B. (P&ID D-100-015).
10.16.2: Add temperature indication between the reforming unit (RU) and the anode on the Fuel Cell Stacks DFC-101A/B. (P&ID D-100-015).
10.16.3: Eliminate the root valves on the differential pressure instruments and pressure gauges on the Fuel Cell Stacks DFC-101A/B and Hot Box M-101. (V-1501, V-1502, V-1503, V-1504, V-1505, V-1506, V-1507)
10.16.4: Connect one leg of the Fuel Cell Stack DFC-101B differential pressure transmitter (DFT-1513) to the cathode exhaust instead of the Hot Box M-101. (P&ID D-100-015)
10.16.5: Provide dual thermocouples all temperature elements on the Fuel Cell Stacks. (P&ID D-100-015)
10.16.6: Evaluate minimizing the number of penetrations (including the 4" startup line) into the Hot Box to minimize congestion in the unit. (P&ID D-100-015)
11.2.1 Increase the design temperature of the Fuel Condenser E-110 to 800°F to protect the equipment if there is no cooling in the HDS Regen Heat Exchanger E-111. (P&ID D-100-010)
11.2.2 Add PLC temperature indication on the hot fuel line between the HDS Regen Heat Exchanger E-111 and the Fuel Condenser E-110 to monitor the operation of E-111. (P&ID D-100-010).
11.5.1 Increase the design temperature of the Desulfurized Fuel Tank (S-102) and piping to 350°F to protect the equipment if there is no cooling in the Fuel Condenser E-110. (P&ID D-100-010)
11.5.2 Make the Fuel Condenser E-110 outlet thermocouple a duplex thermocouple because of the potential to get uncondensed water and fuel in the HDS and ZnO Reactors. (P&ID D-100-010).
11.6.1 If the design is modified to send water out with the liquid fuel, then ensure that the fuel line can be drained during a shutdown in cold weather. (P&ID D-100-010).

11.6.2 Add a drain valve on the bottom of the Desulfurized Fuel Tank S-102 to drain water in the event of a shutdown during cold weather. (P&ID D-100-010).
11.9.1 Eliminate the automatic water draw from the Desulfurized Fuel Tank S-102, by sending it forward with the liquid fuel. (P&ID D-100-010)
11.9.2 Provide an independent level switch on the Desulfurized Fuel Tank S-102 high interlocked to shutdown the P-101 Fuel Pump. (P&ID D-100-010, D-100-005)
11.10.2 Evaluate the design of the water drain line system from the Desulfurized Fuel Tank S-102 and consider adding a separate low level interlock that closes a water drain valve on the line. (P&ID D-100-010)
11.11.1 Investigate the design of Desulfurized Fuel Tank S-102 as a separator to ensure adequate time for the water to settle from the liquid fuel. Or consider designing the tank to keep the water in solution with the liquid fuel. (P&ID D-100-010)
11.17.1: Delete the differential pressure transmitter (DPT-1016) and its isolation valve across the Water Filter F-115. (P&ID D-100-010).
11.17.2: Change the flow control valve (FV-1006) on the Desulfurized Fuel Tank (S-102) water draw line to a on/off valve and add a restriction orifice for the pressure drop. (P&ID D-100-010).
12.3.1 Configure the nitrogen on/off valve (XV-1007) that connects to the HDS Recycle Compressor (B-105) discharge to not be able to be opened unless the pressure in the S-102/HDS Reactor R-101 system (PT-1010) is less than 100 psig to prevent reverse flow. (P&ID D-100-010).
12.7.1 Ensure that the relief device (PSV-609) on the HDS Reactor is sized for blocked outlet. (P&ID D-100-006).
12.14.1: Finish the design of the sample system. Add a quick connect to the hydrogen sample point that stops the flow when disconnected. (P&ID D-100-010)
12.15.1: Move the Hydrogen Filter F-114 directly upstream of the pressure control valve PV-1010 from the main hydrogen line out of S-102. Make the filter a small in-line type and remove the differential pressure transmitter (DPT-1015). (P&ID D-100-010)
12.15.2: Remove the manual block valve (V-1002) on the discharge of the HDS Recycle Compressor (B-105). (P&ID D-100-010)
12.15.3: Provide a vent line and automatic valves on this new line and on the hydrogen vent line downstream of PV-1010, so that when the Prereformer is not operating vapors can be still be vented from the desulfurizing system. The stream should be vented to the Start Burner H-102. (P&ID D-100-010)
13.6.1: Perform a separate HAZOP on the Electrolyzer EL-101 when details regarding its design, interface to the process and operation are known, in order to determine the exact causes for deviation from the design intention. (P&ID D-100-022).
13.13.1: Provide a hydrogen connection to the anodes during the heat-up process when hot gas is going through the cathodes, to keep the anode from being oxidized. (P&ID D-100-022, D-100-015)
13.16.1: Add a flow indicator to the hydrogen line (HYD-SS06-022002) from the Electrolyzer vendor package that connects to the raw fuel line upstream of the HDS Regen Heat Exchanger E-111. (P&ID D-100-010)
13.16.2: Evaluate the pressure control instrumentation provided by the Electrolyzer (EL-101) vendor to ensure no duplication of instrumentation. (P&ID D-100-022, D-100-006)
13.16.3: Provide a hydrogen pressurizing line for the Prereformer R-103. Route through E-102, so that the hydrogen can be heated and will not cool the Prereformer. (P&ID D-100-010, D-100-022)
13.6.4: Evaluate if the hydrogen line out of the Electrolyzer (EL-101) can be reduced from $\frac{1}{2}$ " to 3/8". (P&ID D-100-022)
14.4.1: Configure the PI.C to not allow the desulfurized liquid fuel isolation valve (XV-1021) to open unless there is steam flow and the Prereformer is at the proper operating temperature and pressure. (P&ID D-100-010).
14.4.2: Make desulfurized liquid fuel isolation valve (XV-1021) to have AUTO only capability, and not HOA. (P&ID D-100-010).
14.15.1: Make the operating pressure on 011001, 010003, 010004 equal. (P&ID D-100-010, D-100-016).
14.15.2: Provide provisions for PAC testing by providing a means to flow fuel from Desulfurized Fuel Tank S-102 to an external desulfurized fuel tank. (P&ID D-100-010).
15.5.1: Provide duplex thermocouples for TE-1602 (E-102), TE-1605 (E-105), and TE-1606 (E-106) for increase reliability. (P&ID D-100-016).
15.10.2: Evaluate if there will be control problem with two-phase flow through the 3-way temperature control valve (TV-1602) for the Prereformer Inlet Preheater (E-102). (P&ID D-100-016)
15.12.1: Provide a high temperature alarm on the temperature indication in thermal management duct exhaust (TI-1610) to indicate a fire in the duct. (P&ID D-100-016).
15.12.2: Provide a duplex thermocouple temperature indication in thermal management duct exhaust (TI-1610) for reliability in indicating a fire in the duct. (P&ID D-100-016).
15.16.1: Delete the block valves for the differential pressure transmitter (DPT-1217) on the Prereformer (R-103. (P&ID D-100-012)
16.1.2: Review the steam and recycle flow control philosophy to avoid a low steam to fuel ratio. (P&ID D-100-010, D-100-011).
16.1.3: Have the PLC compare fuel flow to the Prereformer (FE-1004) to the HDS fuel flow (integrate over time) to avoid a low steam to fuel ratio. (FE-501). (P&ID D-100-005, D-100-010).
16.1.4: Have the PLC compare steam flow (FE-1109) to water flow to the boiler (FE-1905) at steady state to ensure accurate steam flow measurement to the Eductors. (P&ID D-100-019, D-100-011)

16.1.6: Evaluate a means to reconcile differences in the PLC between steam flow and power generation for controlling the fuel flow (FV-1004). (P&ID D-100-010).
16.2.1: Determine how the fuel cell will be operated for the regeneration of the Prereformer catalyst including source of hydrogen and water and regeneration temperatures and pressure. Consider the use of raw fuel or HDS operation. (P&ID D-100-012)
16.2.2: Revise the raw fuel flow control (FE-501 and P-101) to include a ramp rate (maximum rate change of flow) to ensure adequate level in S-102 during power step changes. (P&ID D-100-105)
16.2.4: Configure the PLC to alarm and shutdown the unit at a pre-determined low steam flow to prevent a low voltage situation and carbon formation on the Prereformer catalyst. (P&D D-100-019 D-100-011)
16.2.5: Establish a limit on the Prereformer Fuel Filter (F-116) differential pressure indicator and a high alarm. (P&ID D-100-012)
16.7.4: Define unit shutdown for a high pressure in the Prereformer (R-103) due to higher than required steam flow. (P&ID D-100-012, D-100-016)
16.8.2: Evaluate rate of R-103 depressurize for step increase (50 to 100%), rate of temperature drop, composition vs. temperature and pressure.
16.13.1: Define and detail the Prereformer regeneration procedure. (Consider when during shutdown, use of raw fuel and steam pressure). (P&ID D-100-012)
16.13.3: Develop a procedure to depressurize the Prereformer and fuel desulfurizer system at the same time to prevent fuel leakage into the Prereformer. (P&ID D-100-010 D-100-012).
16.15.1: Delete the differential pressure transmitter (DPI-1253) root valves (V-1208, V-1207) on the Prereformer Filter (F-116). (P&ID D-100-012).
16.15.2: Relocate the pressure transmitter (PT-1223) from the inlet of the Prereformer (R-103) to the outlet of the Prereformer. And connect a signal from PI-1223 and DPI-1253 (difference calculates pressure downstream of the F-116) to FC-1301 for the pressure compensation of flow to the Expander Temperature Generator. Also, TE-1213 input needed for FE-1301 for composition to calculate flow if temperature or pressure is different than setpoint. (P&ID D-100-112).
16.15.3: Add a pressure relief valve on the exit of the Boiler (E-106) to protect it from overpressure especially during shutdown. (P&ID D-100-016)
17.2.11: Configure the PLC to interlock the failure of the Start Burner with the Prereformer regeneration mode, so that regeneration will stop when the Start Burner is not operating. (P&ID D-100-015)
17.2.12: Investigate how to mitigate a blocked-in discharge on the Start Burner (H-102). Evaluate if a pressure relief is needed, or combining XV-1406 and XV-1407 as one diverter valve with limit stops. (P&ID D-100-014).
17.10.1: Define the minimum time duration for the Prereformer regeneration at the defined operating conditions. (P&ID D-100-012).
17.13.1: Configure the PCL to stop the Prereformer (R-103) regeneration mode when the Start Burner (H-102) is not in operation. (P&ID D-100-014)
18.1.1: Interlock XV-1306 to close upon high high flow at FE-1301, if flow is not in line with a given cell current.
18.2.1: Define procedures for switching to Dispatch Power Mode.
18.5.2: Turbine Generator Vendor's pkg should include a temperature sensor for monitoring overheating of TG-101.
18.5.3: Evaluate removing the temperature control valves in the Coolant system and replace each control valve with a manual gate or globe valve with a local flow indicator.
18.9.2: Define procedures to purge and vent during shutdown
18.11.1: Evaluate containment of high speed rotating parts.
18.12.1: Develop a startup procedure for the Turbine Generator TG-101. (P&ID D-100-013)
18.13.1: Develop a shutdown procedure for the Turbine Generator TG-101. (P&ID D-100-013)
18.15.1: Add 2" insulation to TG-101. (P&ID D-100-013)
19.2.2: Install a mechanical stop in the Anode Exhaust Condenser coolant temperature control valve TV-1801 to prevent fully closing and damaging the Anode Recycle Blower. (P&ID D-100-018).
19.2.3: Evaluate the use of Buna-N gaskets in the Anode Recycle Blower (B-102) flange gasket for high temperature. Consider replacing with a metal type gasket. (P&ID D-100-018)
20.8.1: Consider alternative to the Condensate Tank S-101 seal leg such as a level control or float valve system for overflow, to avoid the risk of getting air into the system if a vacuum occurs in S-101 or venting hydrogen in the enclosure. (P&ID D-100-022).
20.11.1: Evaluate if the chemistry of adding Electrolyzer water into the Condensate Tank S-101 is an issue due to dissolved hydrogen. Should the Electrolyzer return water be routed to different location? (P&ID D-100-018).
20.11.3: Evaluate if the water recycle returning from the Electrolyzer (EL-101) should be routed to a different location to better utilize the hydrogen (dissolved and degassed) in the water stream. (P&ID D-100-018, D-100-0220).
20.14.1: Consider alternatives to the Condensate Tank S-101 seal leg such as a level control or float valve system for overflow, to avoid the risk of getting air into the system if a vacuum occurs in S-101 or venting hydrogen in the enclosure. (P&ID D-100-022).

21.1.1: Evaluate adding a positive technique to provide cross pressure (high Hot Box to anode differential pressure) relief across the Fuel Cell. Evaluate adding an internal relief on the Anode Recycle Blower (B-102) that senses low pressure on the Blower suction, and then recycles the discharge flow back to the Blower suction. (P&ID D-100-018).	
21.2.2: Evaluate if XV-1405 can be eliminated because if it closes the high pressure will severely damage the anode side of the Fuel Cell. If the XV cannot be eliminated then provide a means to relieve anode overpressure such as a water seal. (P&ID D-100-014, D-100-015).	
21.4.1: Evaluate relocating the tie-in between the anode exhaust system and E-102 for nitrogen warmup, to eliminate the potential for overpressuring the Fuel Cell if the isolation valve (XV-1805) opens. (P&ID D-100-018).	
21.4.2: Evaluate whether a double block and bleed is needed on the anode nitrogen warmup line (XV-1805) between E-108 and H-101 to prevent the valve leaking and allowing fuel into the Catalytic Oxidizer and eventually the cathode. (P&ID D-100-018)	
21.4.3: Move the anode exhaust tie-in (-018011) to before the connection of line -010003 (S-102 hydrogen), so that if XV-1805 leaks then only steam and recycle fuel would be leaked into the Catalytic Oxidizer and eventually the cathode. (P&ID D-100-016).	
21.10.1: Specify the Anode Recycle Blower (B-102) a sealess blower to prevent the risk of hydrogen and CO leaks. (P&ID D-100-018)	
21.12.1: Evaluate if the startup procedure can be simplified to eliminate isolation valves XV- 1405 and XV-1805. (P&ID D-100-014, D-100-018).	
22.4.1: Upgrade the nitrogen line from XV-1806 to and including PCV-522 to 300# to prevent overpressure if XV-1806 opens during normal process operation. (P&ID D-100-005, D-100-018).	
22.4.3: Configure (interlocks) the PLC to prevent the Electrolyzer hydrogen valve (XV-2203) from opening during the nitrogen warm-up of the anode loop to prevent overpressure damage to the Fuel Cells. (P&ID D-100-022).	
22.4.6: Configure (interlocks) the PLC to prevent the Desulfurized Fuel Tank (S-102) hydrogen isolation valve (XV-1024) from opening during the nitrogen warm-up of the anode loop to prevent overpressure damage to the Fuel Cells. (P&ID D-100-010).	
22.4.7: Configure (interlocks) the PLC to prevent the Desulfurizer Fuel Tank liquid fuel isolation valve (XV-1021) from opening during the nitrogen warm-up of the anode loop to prevent overpressure damage to the Fuel Cells. (P&ID D-100-010).	
22.5.1: Make the E-101 outlet temperature element dual thermocouples (TE-1601). (P&D D-100-016).	
22.5.2: Make the E-102 outlet temperature element dual thermocouples (TE-1602). (P&D D-100-016).	
22.6.1: Evaluate if the Air Preheater (E-104) bypass temperature control valve (TV-1604) can be eliminated. (P&ID D-100-016).	
22.7.1: Change the set pressure of PCV-522 from 5 psig to 5" of water column to prevent overpressuring the Fuel Cell during nitrogen warm-up. (P&ID D-100-005).	
22.7.2: Provide a means to relieve anode overpressure caused by the expansion of the nitrogen during heat-up. (P&ID D-100-014, D-100-015).	
22.7.3: Evaluate the failure mode of the nitrogen pressure regulator PCV-522 and determine impact on downstream equipment. (P&ID D-100-005).	
22.8.2: Provide appropriate interlock for mitigating contamination of SO2 (from burning raw fuel) into the Fuel Cells. (P&ID D-100-015).	
22.15.1: Revise the P&ID to indicate that process air control valve TV-1501 is controlled during warm-up nitrogen startup to maintain a pressure in the Hot Box (PI-1511) higher than the cathode exhaust (PI-1521). (P&ID D-100-015).	
23.2.1: Evaluate the capability of the Start Burner (H-102) to run with gaseous fuel rather than liquid fuel during a shutdown. (How will the Prereformer R-103 be depressurized if the Air Blower B-101 is not operating? Vent out of exhaust stack instead?). (P&ID D-100-014).	
23.7.1: Determine how the process air temperature control setpoint will be determined for various ambient temperatures and power loads.	
23.16.1: Evaluate if the Process Air Secondary Filter (F-107) should also serve as a silencer. (P&ID D-100-006).	
24a.1.2: Provide a high temperature shut-off interlock on the outlet (TE-1407) of the Start Burner (H-102) in case of excessive fuel flow. (P&ID D-100-014)	
24a.2.1: Provide a dual thermocouple for the Start Burner (H-102) exhaust (TE-1407) and the Catalytic Oxidizer (H-101) outlet (TE-1402). (P&ID D-100-014)	
24a.2.2: Include the loss of the Process Blower (B-101) in the emergency shutdown procedures/interlocks. (P&ID D-100-006, D-100-014).	
24a.2.4: Evaluate if the Start Burner Air Blower (B-106) can be eliminated (and an isolation valve added), since it is receiving suction from the Process Air Blower (B-101). (P&ID D-100-014). The answer is NO	
24a.2.5: Evaluate if the variable speed drive to the Start Burner Air Blower (B-106) can be eliminated. (P&ID D-100-014).	
24a.6.2: Confirm that Start Burner (H-102) vendor package includes all necessary controls and safeguards to prevent overfiring. (P&ID D-100-014).	
24a.12.1: Evaluate if flexible connections are required around the Start Burner (H-102) for thermal expansion. (P&ID D-100-014).	
24a.15.1: Evaluate if there is a need for emissions sampling on the discharge of the thermal management system. (P&ID D-100-016)	
24a.16.1: Move the raw fuel feed take-off to the Start Burner H-102 from the discharge of the Fuel Pump P-101 to its suction. (P&ID D-100-005).	
24a.16.2: Relocate the Start Burner (H-102) exhaust temperature control valve (TV-1407) take-off from the heated process air to the inlet of the Start Burner Air Blower (B-106). Eliminate the restriction orifice in the process air line to the inlet of the Catalytic Oxidizer (H-101). (P&ID D-100-014)	
24b.1.1: Evaluate if the Start Burner exhaust into the Catalytic Oxidizer (H-101) can be eliminated during startup in order to eliminate the exhaust diverter valve (FV-1406). (P&ID D-100-014)	

24d.1.1: Evaluate if a catalyst bed (i.e., catalytic converter) can be added to the exhaust system to consume the H2S produced from ZnO Reactor regeneration, in order to prevent the need of operating the Start Burner (H-102) during ZnO Reactor regeneration. (P&ID D-100-014)
24e.1.1: Evaluate if the use of the Start Burner (H-102) can be eliminated during the "sustaining" mode by using a higher fuel rate into the Fuel Cell to generate the necessary heat (i.e., lower fuel utilization). (P&ID D-100-014)
24g.1.3: Evaluate how to dispose of the fuel in the prereformer loop during a load drop, emergency shutdown, or FV-1301 failure (open) during shutdown to prevent high temperature damage to equipment due to excessive fuel to the Catalytic Oxidizer (H-101). (Close XV-1405 and vent to the relief vent header? Alternate: Evaluate locking up the fuel?). (P&ID D-100-014)
24g.2.2: Have the Start Burner exhaust (TI-1407) shutdown the liquid fuel valve TV-1402 on high-high temperature. (P&ID D-100-014).
24h.1.3: Define HDS shutdown purge rates, and determine how this rate will be controlled. Should a flow control valve and flow element replace XV-826 to control the depressurization of the HDS system? (P&ID D-100-008)
24h.2.2: Have the Start Burner exhaust (TI-1407) shutdown the liquid fuel valve TV-1402 on high-high temperature. (P&ID D-100-014).
24h.4.1: Evaluate if the Start Burner exhaust into the Catalytic Oxidizer (H-101) can be eliminated during shutdown in order to eliminate the exhaust diverter valve (FV-1406). (Also see recommendation 24b.1.1 regarding eliminating FV-1406 during startup.) (P&ID D-100-014)
24h.4.2: Evaluate if a catalyst bed (i.e., catalytic converter) can be added to the exhaust system to combust H2S and hydrogen during the HDS loop depressurization, in order to prevent the need of operating the Start Burner (H-102) during HDS loop depressurization and the burning of raw fuel. (Also see recommendation 24d.1.1 regarding a thermal management system catalyst bed.) (P&ID D-100-014)
24h.9.1: Evaluate if air (without CO2) through the cathode side of the Fuel Cell during normal shutdown will cause damage. Incorporate into the shutdown procedure the cool-down of the fuel cell before the prereformer loop is shutdown. (P&ID D-100-014).
24h.13.1: Revise the normal shutdown procedure to include a step for regenerating R-103.
24h.13.2: Evaluate if a controlled rate of cool-down for the Fuel Cell stacks is required. Is a fast cool-down required for maintenance, or can flows be isolated and the system cooled down through normal heat loss?
25.5.2: Develop operating procedures to ensure that the Fuel Evaporator (E-105), Boiler (E-106), Feedwater Heater (E-107) and the Condensate Heater (E-116) are no damaged during startup or shutdown.
25.9.3: Add an activated charcoal filter (F-118) to remove trace hydrocarbons from the anode condensate. Locate on the discharge of Water Treatment Pump (P-105). (P&ID D-100-019).
25.14.1 Add manual block valves to Coarse Filter (F-103) for maintenance. (P&ID D-100-018).
25.15.1: Provide a drain on the Condensate Tank (S-101) that can also serve as a manual sample point. (P&ID D-100-018).
26.3.1 Evaluate if a check valve is required on the Water Treatment Pump (P-105) recirculation line to prevent reverse flow and non-demineralized water into the system. (P&ID D-100-019).
26.5.1: Evaluate raising the design temperature of the Water Treatment Pump (P-105) and the Demineralizer (WT-102) to 300 degrees F in case there is a loss of cooling in the Water Treatment Cooler (E-115) P&ID D-100-019).
26.7.3: Increase the design pressure of the Water Treatment Pump (P-105) from 30 psig to 50 psig, in order to protect the pump in case it is dead-headed. (P&ID D-100-019)
26.12.1: Add a high point vent to the Demineralizer (WT-102) to vent air from the system during startup. (P&ID D-100-019)
26.15.1: Make the design of the Demineralizer (WT-102) to be a dual unit with replaceable cartridges. Provide a Fine Filter (F-104A/B) downstream of each cartridge. Relocate the conductivity meter (CI-1916) downstream of the Fine Filters (F-104A/B). (P&ID D-100-019)
26.15.2: Ensure that the Fine Filter (F-104) and the Activated Charcoal Filter (F-118) can be accessed for periodic maintenance.
26.15.3: Relocate the Demineralizer (WT-102), Fine Filter (F-104A/B) and the Activated Charcoal Filter (F-118) off the module because the proposed unit is too large. (P&ID D-100-019)
27.7.1: Add a relief device to the steam/water side of the Boiler (E-106) to prevent overpressure damage in case the system is isolated and expands due to heat from the thermal management system. Relieve the relief device to the exhaust duct of the thermal management system. (P&ID D-100-016)
28.4.5: Evaluate adding a water seal relief on the Fuel Cell anode side (at the discharge of the anodes) to prevent overpressure from a process upset. (P&ID D-100-015)
28.5.1: Ask Eductor (EJ-101) vendor if the steam flow should be gradually added to prevent thermal shock damage, and request recommended startup procedure. Can this be accomplished with the pintle set at the lowest setting. (P&ID D-100-011).
28.5.2: Evaluate if the Eductor recycle line check valve CK-1103 should have a minimum stop to allow a small amount of nitrogen warm-up flow during startup. Or can the check valve be eliminated if the pintle will restrict nitrogen warm-up flow. Also provide temperature indication to indicate that the Eductor is warming up. (P&ID D-100-011).
28.5.3: Evaluate if the Eductor (EJ-101) internals are suitable for nitrogen heating start-up as well as normal operation temperatures. (P&ID D-100-011)
28.12.1: Add a steam trap to the low point on the steam line to the Eductor to remove any condensate that collects during shutdown, so that downstream equipment will not be damaged. (P&ID D-100-011)

28.15.1: Relocate the steam flow element on the outlet of the Boiler (E-106) downstream of the take-off for the steam startup line in order to sense flow if XV-1105 is open at the wrong time (during startup).
29.9.1: Ensure that the Startup Polisher (H-104) has a removable catalyst tray, so that the catalyst can be removed for maintenance. (P&ID D-100-016) ??
29.9.2: Evaluate the need for the Startup Polisher (H-104). Can it be eliminated? (P&ID D-100-016) ????
29.15.1: Relocate the cathode exhaust to the 10" exhaust line from the thermal management system. (P&ID D-100-016)
29.15.2: Relocate the nitrogen/cathode exhaust from E-118 10" exhaust line from the thermal management system. (P&ID D-100-016)
30.2.2: Provide a temperature indication (TI-1315) and high alarm on the nitrogen cooling loop for the TG-101 between the Generator and the Nitrogen Cooler (E-119). (P&ID D-100-013)
30.2.3: Determine the failure mode of self contained pressure regulators especially in nitrogen service. If the failure mode is opposite than desired, then replace with pressure control valve and pressure sensor.
30.3.2: Add a check valve (CK-1301) to the nitrogen line to the TG-101 nitrogen cooling system. (D-100-013)
30.3.3: Add a check valve (CK-901) to the nitrogen line to the ZnO Reactor regen system. (D-100-009)
30.3.4: Add a check valve (CK-1302) to the nitrogen line to the TG-101 outlet between XV-1310 and the process fuel line. (P&ID D-100-013)
30.4.1: Evaluate if a flow meter is required for the nitrogen supply. (P&ID D-100-005)
30.8.1: Re-evaluate nitrogen line sizes if the downstream pressure of the nitrogen supply PCV-504 is changed from 100 psig to 40 psig. (Is 40 psig adequate for the Electrolyzer EL-101?). (P&ID D-100-005)
30.14.1: Ensure that the nitrogen isolation valve V-517 can be locked for lock-out/tag-out procedures. (P&ID D-100-005)
30.15.1: Evaluate having a single 5 psig nitrogen header by combining PCV-526 and PCV-519 into a single PCV. (P&ID D-100-005)
30.15.2: Change the downstream pressure of nitrogen supply PCV-504 from 100psig to 40 psig, and delete PCV-916 (ZnO regen system). P&ID D-100-005, D-100-015)
30.15.3: Evaluate if a vortex meter is a better application for nitrogen flow measurement rather than a flow orifice. (FE-1314, FE-521, FE-512). (P&ID D-100-005, P&ID D-100-013)
30.15.4: Ensure that there are local pressure gauges (PI) downstream of every nitrogen pressure regulator. (PCV-526, PCV-504, PCV-522, PCV-1312)
31.14.1: Determine the location and response time of the combustible gas detectors, temperature sensors and the CO2 fire suppression system. (P&ID D-100-005)
31.14.2: Connect the fire suppression system to the PLC. (P&ID D-100-005)
32.11.2: Evaluate filling the relief system and the Relief KO Pot with CO2 as an inerting atmosphere rather than having continuous nitrogen purge. (P&ID D-100-023)
32.17.1: Evaluate if the relief stream out of the HDS Reactor will contain a liquid phase, to determine if the Relief KO Pot S-103 can be deleted. (P&ID D-100-023)
33.17.1: Show the electric resistance heater (H-109) on the HDS Reactor R-101B. (P&ID D-100-017)
33.17.2: Add note 3 to the temperature elements (duplex elements) on the HDS Reactor R-101B. (P&ID D-100-017)
33.17.3: Add 2" insulation to HDS Reactor R-101B. (P&ID D-100-017)
33.17.4: Delete the HDS Filter F-119 because there are no XV valves to be protected from plugging. (P&ID D-100-017)
34.14.1: Since HDS Filter F-119 and the manual isolation valves between the HDS Reactor (R-101B) and the ZnO Reactor (R-102C) are removed, consolidate the relief devices on both reactors to single relief device. Ensure that line between reactors is sized to prevent excessive pressure drop during relief. (P&ID D-100-017)
34.14.2: Eliminate the temperature indicators TI-1708 and TI-1710 on the ZnO Reactor (R-102C), but keep the thermowells (TW) on the vessel, so that it can be specified identical to the other ZnO Reactors. (P&ID D-100-017)
33.14.3: Show the electric resistance heater (H-109) on the HDS Reactor R-101B. (P&ID D-100-017)
33.14.4: Add note 3 to the temperature elements (duplex elements) on the HDS Reactor R-101B. (P&ID D-100-017)
33.14.5: Add 2" insulation to HDS Reactor R-101B. (P&ID D-100-017)
35.4.11: HAZOP the operation of the block valve XV-826 to the Start Heater (H-102) when the design is finalized. (P&ID D-100-008)
35.5.1: Ensure that the ZnO Reactor regeneration system has adequate overpressure protection in case a block and bleed combination fails causing high pressure fuel from the operating process into regen system. Consider the use of excess flow valves to restrict flow. (P&ID D-100-009).
35.12.1: Evaluate if the 2" startup lines for R-101A/B and R-102C can be reduced in size (in order to save room), since 40 psig nitrogen is being used to heat the system for startup. (P&ID D-100-006, D-100-007, D-100-008, D-100-009, D-100-017).
35.12.2: Evaluate if the 2" startup lines for R-101A/B and R-102A/B/C can be eliminated (in order to save room), and the process lines used for startup heatup. Evaluate if blower (B-105) capacities can be altered and/or more electric heat added for startup. (P&ID D-100-006, D-100-007, D-100-008, D-100-009, D-100-017).

35.15.1: Provide dual thermocouples for the reactor Electric Heaters (P&ID D-100-006, D-100-007, D-100-008, D-100-017).
38.1.1: Define the set limits for the combustible and carbon monoxide analyzers in the enclosure, Hot Box and the exhaust duct. (P&ID D-100-005, D-100-015, D-100-016)
38.2.1: Provide an audible local alarm horn for the Gas Monitor. (P&ID D-100-005)
39.3.1: Indicate minimum distance on P&ID to prevent deadleg of liquid fuel downstream of XV-1021.
39.5.1: If Process Air Blower B-101 is being reduced in speed for temperature control, air to the Start Heater (H-102) is also being reduced. Decouple the connection of B-101 to B-106.
39.7.1: Revise the Catalytic Oxidizer (H-101) outlet temperature control by having TE-1402 control the Process Blower B-101 speed and not be an input to liquid fuel valve TV-1402. (P&ID D-100-014)
39.7.2: Provide new H2 and N2 connections for anode. (Currently not provided).
39.9.1: Change steam vent PV-1121 to PCV-1121 to a pressure control valve.
39.14.1: Configure the PLC to have the Electrolyzer sweep the fuel line for several minutes after P-101 stops for shutdown
39.15.1: indicate minimum distance on P&ID between fuel XV-52 and check valve C-1003 to prevent deadleg of liquid fuel on P-101 discharge after shutdown.
39.18.1: Will the liquid capacity of S-102 be exceeded?

C. Piping and Instrument Diagrams

The P&IDs and sketches reviewed during the HAZOP were as follows:

Drawing TITLE	P&ID NO./Revision
P&ID - Fuel Feed	D-100-005 rev. B, rev. C
P&ID - Desulfurization – HDS / Process Air	D-100-006 rev. B
P&ID - Desulfurization R-102A	D-100-007 rev. B
P&ID - Desulfurization R-102B	D-100-008 rev. B
P&ID - ZnO Regeneration System	D-100-009 rev. B
P&ID - Desulfurization – Fuel Storage	D-100-010 rev. B, rev. C
P&ID - Processed Fuel Eductors	D-100-011 rev. B
P&ID - Prereformers	D-100-012 rev. B
P&ID - Expander Turbine Generator	D-100-013 rev. B, rev. C
P&ID - Catalytic Oxidizer / Start Burner	D-100-014 rev. B
P&ID - Fuel Cells / Hot Box	D-100-015 rev. B
P&ID - Thermal Management	D-100-016 rev. B
P&ID - HDS and ZnO Polishing Reactors Anode Exhaust Regenerator	D-100-017 rev. C
P&ID - Water Recovery	D-100-018 rev. B
P&ID - Water Treatment	D-100-019 rev. B
P&ID - Coolant System	D-100-020 rev. B
P&ID - Instrument Air System	D-100-021 rev. B
P&ID - Electrolyzer	D-100-022 rev. B
P&ID - Rclifc Vcnt Hdacer	D-100-023 rev. C
Sketch – Start Heating	rev. 9-8-01
Sketch – Operation and ZnO Regen	rev. 9-8-01
Sketch – Zn Regen Purge Step	rev. 9-8-01

The HAZOP primarily reviewed the revision B P&IDs with mark-up as illustrated in the attached P&IDs. By the end of the HAZOP review revision C of the P&IDs were being issued, however they were only utilized for the study nodes that had not yet been reviewed.

The HAZOP was a review of the “snap-shot” of the design, so changes to the P&IDs as a result of HAZOP action items were not reviewed, and hence are not indicated in the attached P&IDs. Once these changes have been approved and implemented onto the P&IDs, the HAZOP logsheets should be revised by the HAZOP team to ensure that the change does not create a new hazard.

D. Acronyms

BOP	Balance of plant
FCE	FuelCell Energy Inc.
FMEA	Failure modes and effects analysis
HAZOP	Hazard and Operability Study
JAT	Jacobs Advanced Technology
MSDS	Material Safety Datasheet
P&IDs	Piping and Instrument Diagrams
PF	Process Flow Diagrams
PPE	Personal Protective Equipment

Appendix Number	Topic and Description	Training Module
A20	Maintenance and spare parts list	Lab #5 Shipboard #5

SSFC 625 KW POWER PLANT		MAINTENANCE AND SPARE PARTS SUMMARY							
		ITEM	NUMBER	REQUIRED MAINTENANCE	TASK FREQUENCY	TIME DURATION	SHUTDOWN REQUIRED	DOCUMENTATION	SPARE PARTS REQUIRED
12/16/2004 9:17									
REV 2 NOV 22, 2002	F HOROWITZ								
POWER CONDITIONING SYSTEM		N/A	none		N/A	N/A	N/A	POWER SYSTEMS	
CENTRAL CONTROL SYSTEM		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	One complete variable speed drive for size less than 3 HP. One spare control board for each type of larger size variable speed drives. One thermocouple card for the PLC. One analog-in card for the PLC. One analog-out card for the PLC. One digital-in card for the PLC. One communication adapter for the PLC.
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
MOTOR CONTROL CENTER		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
VFD EQUIPMENT		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	Two power supplies for the PLC. One motherboard for the liquid crystal display. One hard drive for the liquid crystal display. Two fuses of each type.
ELECTRICAL EQUIPMENT		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
GENERAL		N/A	none		N/A	N/A	N/A	ALLEN BRADLEY	
INVERTER		N/A	lubricate bearings	5000 hrs	5000 hrs	0.25 NO	BARBER-NICHOLS	VARIOUS MFRR.	
PROCESS AIR BLOWER		B-101	replace bearings and o rings	5000 hrs	5000 hrs	4 YES	BARBER-NICHOLS	Insulation, gaskets, packing/seals for valves.	
PROCESS AIR BLOWER		B-101	lubricate bearings	3300 hrs	3300 hrs	0.25 NO	BARBER-NICHOLS	Insulation, gaskets, packing/seals for valves.	
ANODE RECYCLE BLOWER		B-102	replace bearings and o rings	3300 hrs	3300 hrs	4 YES	BARBER-NICHOLS	Bearings, o rings, spring	
ANODE RECYCLE BLOWER		B-102	lubricate bearings			0.25 NO	AIRTECH/SIEMENS	Shaft packing/seal, lubricant	
ZNO REGENERATION BOOST BLOWER		B-103	lubricate bearings			0.25 NO	AMERICAN FAN	Shaft packing/seal, lubricant	
MBOP VENTILATING FAN		B-104	lubricate bearings	4500 hrs	4500 hrs	0.25 NO	BARBER-NICHOLS	Lubricant	
HDS RECYCLE COMPRESSOR		B-105	lubricate bearings	18,000 hrs	18,000 hrs	4 YES	BARBER-NICHOLS	Bearings, o rings, spring	
HDS RECYCLE COMPRESSOR		B-105	replace bearings			0.25 NO	ROTRON	Shaft packing/seal, lubricant	
START BURNER AIR BLOWER		B-106	lubricate bearings			0.25 NO	TREADWELL	Shaft packing/seal, lubricant	
ELECTROLYZER CABINET VENT FAN		B-107	lubricate bearings			0.25 NO	FUEL CELL ENERGY	Lubricant	
FUEL CELLS		DFC 101 A&B	none		N/A	N/A	N/A	HUGHES TREITLER	none
PROCESSED GAS HEATER		E-101	none		N/A	N/A	N/A	HUGHES TREITLER	rupture disk
PREFEFORMER INLET PREHEATER		E-102	none		N/A	N/A	N/A	HUGHES TREITLER	none
AIR PREHEATER		E-104	none		N/A	N/A	N/A	HUGHES TREITLER	none
FUEL EVAPORATOR		E-105	none		N/A	N/A	N/A	HUGHES TREITLER	none
BOILER/FEDDATER HEATER		E-106/E-107	none		N/A	N/A	N/A	HUGHES TREITLER	rupture disk
ANODE EXHAUST REGENERATOR		E-108	none		N/A	N/A	N/A	H S MARSTON	none
ANODE EXHAUST CONDENSER		E-109	none		N/A	N/A	N/A	H S MARSTON	none
FUEL CONDENSER		E-110	none		N/A	N/A	N/A	H S MARSTON	none
HDS REGENERATIVE HEAT EXCHANGER		E-111	none		N/A	N/A	N/A	H S MARSTON	none
SEA WATER HEAT EXCHANGER		E-112	none		N/A	N/A	N/A	SCMITT BRETON	none

SSFC 625 KW POWER PLANT		MAINTENANCE AND SPARE PARTS SUMMARY					
ITEM	ITEM NUMBER	ITEM	REQUIRED MAINTENANCE	TIME FREQUENCY	DURATION	SHUTDOWN REQUIRED	DOCUMENTATION
ZNO REGENERATION COOLER	E-114	none	N/A	N/A	N/A	N/A	H S MARSTON
WATER TREATMENT COOLER	E-115	none	N/A	N/A	N/A	N/A	H S MARSTON
CONDENSATE HEATER	E-116	none	N/A	N/A	N/A	N/A	HUGHES TREITLER
ZNO REGENERATION RECUPERATOR	E-118	none	N/A	N/A	N/A	N/A	H S MARSTON
FUEL CONDENSER	E-120	none	N/A	N/A	N/A	N/A	H S MARSTON
FUEL EDUCTOR	EJ-101	none	N/A	N/A	N/A	N/A	GRAHAM
ELECTROLYZER	EL-101	Replace F-201 element	6 MONTHS	0.25	YES	TREADWELL	Digital IC card, analog input card,CPU card,
ELECTROLYZER	EL-101	Replace deionizer bed	6 MONTHS	0.5	YES	TREADWELL	motherboard card, display/control board card,
ELECTROLYZER	EL-101	Lubricate feed pump	12 MONTHS	0.25	YES	TREADWELL	solenoid valves NO, solenoid valves NC,
ELECTROLYZER	EL-101	Replace electronics		1	YES	TREADWELL	pressure transducer, thermocouple, flow sensor
ELECTROLYZER	EL-101	Replace solenoid valves		2	YES	TREADWELL	gas analyzer detectors H2 and O2, filter cartridge
INLET AIR FILTER	F-101	Replace filter element	6 MONTHS	0.25	NO	TREADWELL	deionizer resin.
FUEL FILTER	F-102	Replace filter element	6 MONTHS	0.25	NO	AAF INTERNATIONAL	
COARSE FILTER	F-103	Replace filter element	6 MONTHS	0.25	NO	ROSEDALE	
START BURNER AIR FILTER	F-106	Replace filter element	6 MONTHS	0.25	NO	ROSEDALE	
PROCESS AIR SECONDARY FILTER	F-107	Replace filter element	6 MONTHS	0.25	NO	ROTRON	
HDS FILTER	F-108	Replace filter element	6 MONTHS	0.25	YES	BARBER-NICHOLS	
ZNO FILTER	F-110	Replace filter element	6 MONTHS	0.25	YES	PUROLATOR FACET	
ZNO FILTER	F-111	Replace filter element	6 MONTHS	0.25	YES	PUROLATOR FACET	
ZNO FILTER	F-112	Replace filter element	6 MONTHS	0.25	YES	PUROLATOR FACET	
ZNO FILTER	F-113	Replace filter element	6 MONTHS	0.25	YES	PUROLATOR FACET	
HYDROGEN FILTER	F-114	Replace filter element	6 MONTHS	0.25	YES	PUROLATOR FACET	
RECYCLE FUEL FILTER	F-116	Replace filter element	6 MONTHS	0.25	YES	PUROLATOR FACET	
COOLANT FILTER	F-121	Replace filter element	6 MONTHS	0.25	YES	ROSEDALE	
CATALYTIC OXIDIZER	H-101	none	N/A	N/A	N/A	PROTOTECH	
START BURNER	H-102						UNIFLOW EXOTHERM
ZNO REGENERATION HEATER	H-103	Replace rupture disk	6 MONTHS	1	YES	DITTMAN & GREER	Fuel and atomizing air elements
HDS START HEATER (R-101)	H-105	none	N/A	N/A	N/A	ACCUTHERM	rupture disk
ZNO START HEATER (R-102A)	H-106	none	N/A	N/A	N/A	ACCUTHERM	none
ZNO START HEATER (R-102B)	H-107	none	N/A	N/A	N/A	ACCUTHERM	none
PREREFORMER START HEATER	H-108	none	N/A	N/A	N/A	ACCUTHERM	none
HOT BOX	M-101	none	later	later	later	N/A	none
FUEL PUMP	P-101	later				later	later

SSFC 625 KW POWER PLANT		MAINTENANCE AND SPARE PARTS SUMMARY							
		TASK				TIME			
ITEM	ITEM NUMBER	REQUIRED MAINTENANCE	FREQUENCY	DURATION	SHUTDOWN	DOCUMENT-ATION	SPARE PARTS REQUIRED		
CONDENSATE PUMP	P-102	Replace bearings and gaskets	36 MONTHS	4	YES	MAGNATEX	bearings, gaskets		
BOILER FEED PUMP	P-103	later	later	later	later	later	later		
COOLANT PUMP	P-104	Lubricate	12 MONTHS	0.25	NO	GOULDS	Lubricant		
WATER TREATMENT PUMP	P-105	Replace bearings and gaskets	36 MONTHS	4	YES	MAGNATEX	bearings, gaskets		
HDS REACTOR	R-101	Replace rupture disk	6 MONTHS	1	YES	WARD TANK	Rupture disk, gasket		
ZNO REACTOR	R-102A	Replace rupture disk	6 MONTHS	1	YES	C H MURPHY	Rupture disk, gasket, ZNO catalyst		
ZNO REACTOR	R-102B	Replace rupture disk	6 MONTHS	1	YES	C H MURPHY	Rupture disk, gasket, ZNO catalyst		
PREREFORMER	R-103	Replace rupture disk	6 MONTHS	1	YES	C H MURPHY	Rupture disk, gasket		
CONDENSATE TANK	S-101	none	N/A	N/A	N/A	GASPAR	none		
DESULFURIZED FUEL TANK	S-102	Replace rupture disk	6 MONTHS	1	YES	WARD TANK	rupture disk		
ZNO DEPRESSURIZATION SEPARATOR	S-104	Replace rupture disk	6 MONTHS	1	YES	WARD TANK	rupture disk		
TURBINE GENERATOR	TG-101	Replace bearings	9,000 hrs	4	YES	BARBER-NICHOLS			
COOLANT SURGE TANK	V-102	none	N/A	N/A	N/A	BLACOH	none		
STACK A VOLUME SIMULATOR	V-106	Replace rupture disk	6 MONTHS	1	YES	GASPAR	none		
STACK B VOLUME SIMULATOR	V-107	Replace rupture disk	6 MONTHS	1	YES	GASPAR	none		
WATER FOG FIRE SUPPRESSION SYSTEM	V-108	later	later	later	later	SECURIPLEX			
DEGASIFIER	WT-101	Replace rupture disk	6 MONTHS	1	yes	WARD TANK	rupture disk		
DEMINERALIZER	WT-102	Replace filter element	6 MONTHS	0.25	NO	TENERGY	12 filter elements		
DEMINERALIZER	WT-102	Replace carbon bed (city water)	3 MONTHS	0.5	NO	TENERGY	2 carbon beds		
DEMINERALIZER	WT-102	Replace carbon bed (anode condensate)	3 MONTHS	0.5	NO	TENERGY	carbon beds included in above.		
DEMINERALIZER	WT-102	Replace deionizing bed (city water)	2.34 DAYS	0.5	NO	TENERGY	2 deionizer resin beds		
DEMINERALIZER	WT-102	Replace deionizing bed (anode condensate)	22.5 DAYS	0.5	NO	TENERGY	deionizer resin bed included in above.		
COOLING SYSTEM TREATMENT UNIT	WT-103					FULLER ULTRAVIOLET	UV lamp		